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PRICE WILLIAMS

ON THE

PERMANENT WAY OF RAILWAYS.

ON THE

PERMANENT WAY OF RAILWAYS.

BY

R. PRICE WILLIAMS, M. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY
JAMES FORREST, ASSOC. INST. C.E.,
SECRETARY.

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THE INSTITUTION OF CIVIL ENGINEERS.

SECT. I.—MINUTES OF PROCEEDINGS.

May 23, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,479.—"On the Permanent Way of Railways." By R. PRICE WILLIAMS, M. Inst. C.E.

WHEN, ten years since, the subject of the maintenance and renewals of permanent way was discussed at this Institution, steel rails may be said to have been on their trial. In the few instances where they had then been used, they were laid down rather as an experiment at stations, and in situations where, from the slow speed of the traffic, no risk was incurred of those sudden fractures to which it was feared their brittle character rendered them peculiarly liable. Experience, however, has shown that these fears were groundless, and that steel, with the small percentage of carbon used for rails, is a material greatly superior to iron, both in strength and durability, and not more liable to sudden fracture.

At the present time, where the traffic is heavy and concentrated, steel rails have entirely superseded iron rails in the renewals of the permanent way; and already the main lines of the London and North-Western, the Great Northern, and other principal railways have been to a great extent relaid with this material; the recent reduction in the cost of manufacture renders it probable that, ere long, steel will be exclusively used for the manufacture of rails.

The Author showed in 1865 that the average life of iron rails on certain portions of the Great Northern railway only amounted to three years.[1] Such, however, has been the growth of traffic in the meantime on this railway, that the tonnage of goods and minerals has been nearly trebled;[2] while on the North-Eastern, the Midland, and the Manchester, Sheffield and Lincolnshire railways, the increase has been even greater, the tonnage in the case of the latter company having been, in the same period, more than trebled.[1]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 361.

[2] 177·34 per cent increase. See Table 1, Appendix.

Having regard to the fact that, ten years ago, the life of iron rails on some of the most heavily worked lines of railway was barely three years, it is questionable whether now, with three times the amount of traffic, it would be possible to carry it on without steel rails.

That this large additional tonnage should have been attended with a proportionate augmentation of the cost of the maintenance and renewals of the permanent way is only what might have been expected, even had there not been a general advance in the price of labour and materials. It is, however, worthy of note that, on all the railways dealt with in this Paper, the cost per mile of maintenance and renewals has not risen in the same proportion; a fact which testifies to the more durable character of the materials employed, and to the consequent saving in the labour of maintenance.

From Table 2 in the Appendix, giving the increase in the cost during the last ten years of the maintenance and renewals on nine of the principal English railways, it will be seen that whereas the Great Northern tonnage has risen 177·34 per cent., the cost per mile of the maintenance and renewals of the permanent way has only increased 49 per cent. Again, on the Midland, while the tonnage has been in a similar period more than doubled,[2] the increase in the cost of maintenance and renewals has only been 64 per cent., the chief portion being due to the substitution latterly of heavier and more durable materials, especially steel rails, the advance in the cost of labour having only amounted to 51 per cent., while in the cost per mile of the materials in the same period it has been 92 per cent. This is still more strikingly shown in the case of the Manchester and Sheffield railway, where, notwithstanding the tonnage has been more than trebled during the last ten years,[3] the total charges under the head of maintenance and renewals of way have only risen 66·68 per cent. Here again the principal part of the increase has been in the cost of materials (73 per cent.), the cost per mile of the labour having, during the last six years, only advanced 34·34 per cent.

The relatively small increase in the cost per mile for labour is also observable in some of the railways south of the Thames;

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[1] 219·05 per cent. increase. See Table 1, Appendix.

[2] 113 per cent. increase. See Table 1, Appendix.

[3] 219 per cent. See Table 1, Appendix.

on the South-Eastern, for instance, it has only been 0·15 per cent., as compared with 45·93 per cent. in materials. The increase in the total charges for maintenance and renewals of way on this railway has only amounted to 1·69 per cent. during the last ten years, as compared with 71·49 per cent. in the tonnage.

On the London and Brighton railway, the rise in the cost per mile for wages during the last six years has been only 6·04 per cent., while the cost per mile for materials has increased 77·18 per cent. A considerable advance, however, has occurred in the staff and office charges on some of the lines south of the Thames, amounting, on the London and South-Western, to 53·61 per cent., and on the South-Eastern to 43·14 per cent. per mile; but the London and Brighton shows a decrease of 39·18 per cent. On the lines north of the Thames, also, there has been a decrease under this head on the North-Eastern and the Great Northern railways.

In the latter half of the year 1868, when railway companies were obliged to adopt a uniform system for their half-yearly reports, besides other important alterations, the distinction between the maintenance and renewals of permanent way was abolished; while the cost of the maintenance and renewals of sidings, points and crossings, previously included under the head of station works, now properly forms part of the charges for maintenance and renewals of way.

To compare the cost of the different items included under the head of permanent way, in the new and the old form of half-yearly reports, the Author has, for the years preceding 1868, as far as possible arranged the tables and diagrams in accordance with the altered form of reports.

In order, however, fairly to contrast the cost of maintenance and renewals on different railways, much more is required than the present uniformity in the half-yearly reports. The gradients, weight, and speed of traffic of each railway have to be considered, as also the proportion of double to single miles of line; and further, the relative mileage of sidings, and the mileage of triple and quadruple lines, which varies considerably; for while the cost of their maintenance and renewal is included under this head in the half-yearly reports, no account is taken of the mileage of either the sidings or the relief lines.

On the other hand, according to the usual method of estimating the cost of maintenance and renewals a mile of single line counts for as much as a mile of double line; the assumption being that, as it carries traffic both ways, the amount of wear and tear, and the consequent cost of repair, must necessarily be equal to that on each of the double lines of way.

To afford a common basis for comparison, and at the same time to enable a reliable estimate to be made of the life values of the permanent way on different railways, the Author has in the tables given the cost of maintenance and renewals, both per mile of railway and per mile of single line.

Table 3, giving the cost of maintenance and renewals per mile of railway, during the last ten years shows, in all cases, much greater variation than the cost per mile of single line; not only does the proportion of single line vary considerably on different railways, but also on the same railway at different periods; for instance, the mileage of single line on the Great Northern railway in 1865 was 22·5 per cent.[1] of the total length maintained, whereas in 1875 it amounted to 21·7 per cent.[2] The charge for maintenance and renewals per mile of single line in the former year was 56½ per cent. of the cost per mile of railway; while in the latter year it was 56 per cent. On the London and Brighton railway the proportion of single line to the total mileage of railway maintained was only 20·9 per cent.[3] in 1865, as compared with 27·7 per cent. in 1875;[4] while the mileage of five, four, and three lines of way, which in the former year amounted altogether to only 29½ miles of single line, had increased in 1875 to 67½ miles; similarly the average charge for maintenance and renewals per mile of single line, which in 1865 was 53 per cent. of the cost per mile of railway, amounted in 1875 to 55 per cent.

"MONEY LIFE" OF THE PERMANENT WAY ON THE GREAT NORTHERN.

The cost of relaying a mile of single line on the Great Northern in 1865, when iron rails were used, was £1,371 (credit being allowed for the old materials); while the average cost of the maintenance and renewals of a mile of single line in the same year was £134·98.[1] In this latter amount, however, is included the staff and office charges, £10·82 per mile; deducting one-half of these as attributable to station works and works of line, and further deducting £12·36 per mile, on account of the maintenance and renewals of the sidings, points, and crossings,[2] there remains a sum of £117·21 per mile as the annual cost of maintaining and renewing the 769 miles of single line on the Great Northern at that time. Dividing £1,371, the net cost of the renewals of a mile of single line, by this annual cost, gives exactly 11·7 years as the average "money life" of the permanent way on the Great Northern system at that time: in other words, such an annual sum was then being spent as would renew the entire mileage of the railway in little less than twelve years.

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[1] Miles.
341 double lines.
99 single ,,
440 railway.

[2] Miles.
438½ double lines.
122¼ single ,,
560¾ railway.

[3] Miles.
195¾ double line.
51¾ single ,,
274½ railway.

[4] Miles.
251¼ double line.
96¼ single ,,
347½ railway.

In 1875, when steel rails were used at £10 per ton, the net cost of relaying a mile of single line was £1,626·283; the cost of maintenance and renewals, after making the deductions in respect of staff and office charges, sidings, &c., already alluded to, was £181·91 per mile; so that the average "money life," for the whole of the 999¼ miles of single line belonging to this company, was only nine years.

Athough the "money life" of the Great Northern permanent way appears to have diminished during the last ten years, it should be remembered that, up to the present time, scarcely one-half of the main line has been relaid with steel rails, and that the iron rails are exposed to the wear and tear of a largely increased traffic; while on the Loop and the East Lincolnshire lines, where the traffic is comparatively light, the original iron rails laid down in 1848, although for the most part still serviceable, are beginning to fail rapidly, and consequently more labour is required in the maintenance of those lines.

That the rise in the price of labour during the last few years has contributed to diminish the "money life" of the permanent way on the Great Northern, as on other railways, there can be no doubt; but the chief cause is due to the increased amount of labour in maintaining the substructure and upholding the surface of the road, through the too yielding nature of the ballast, which, while it constitutes the longest lived portion of the permanent way, is at the same time unquestionably the weakest and most expensive.

By reference to Plate 15, showing the cost of the maintenance, and of the maintenance and renewals of sidings, &c., separately from that of the renewals of way, it will be seen that the labour in maintenance amounts to four times the labour required in the renewals.

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[1] Mean of two half-years, Table 3, Appendix.

[2] *Vide* Plate 15.

For the purposes of comparison, the cost of the maintenance and renewals of the permanent way of nine of the principal English railways is given, in a condensed form, in Table 3 in the Appendix. The average cost per mile during the last ten years has been highest on the Lancashire and Yorkshire railway, and the "money life" of its permanent way is consequently the shortest, viz., 6·78 years; whilst the maximum "money life," 10·68 and 10·61 years, and the least cost per mile, is on the South-Eastern and the London and Brighton railways. The average annual cost per mile of single line, during the last ten years on the nine railways, has been £157·52; dividing £1,395·67, the net cost of the renewals of a mile of single line with iron rails, and taken at their average price (viz. £7 10*s.*), by this annual cost, it will be found that the mean "money life" of the permanent way of all these railways has only been 8·86 years.

The total expenditure during 1875, in maintaining and renewing the permanent way of these nine railways, with their 6,622 miles of railway or 11,705½ miles of single line, was £2,500,701,[1] or an average of £213·64 per mile of single line. Assuming that steel rails were used for the renewals, which obviously could not have been the case, and that the cost of renewing a mile of single line with steel rails at present prices is £1,626·283 per mile, it follows that the present "money life" of nearly one-half the railway mileage in the kingdom does not amount to more than 7¾ years, and that such a sum must be expended in that short period as would suffice to renew the whole of the permanent way of these railways with steel rails. Since the annual cost of the maintenance and renewals of the permanent way represents $2\frac{1}{10}$ per cent.[1] interest on the ordinary capital of these railway companies, and one year's increased "money life" of the permanent way is equivalent to an addition of ¼ per cent. interest upon this capital, the importance of the efforts now made to render the permanent way more durable, and less expensive to maintain, will not fail to be recognised.

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[1] See Table 4 in the Appendix.

[2] The ordinary capital of the nine railway companies in 1875 was £119,558,959. The amount expended in maintenance and renewals in 1875 was £2,500,701. See Table 4 in the Appendix.

LIFE OF IRON RAILS.

The average actual life of the permanent way, or of the materials which constitute it, should not be confounded with what is termed the "money life," the latter being merely a co-efficient to determine the annual cost per mile of the maintenance and renewals in terms of the net cost of the construction.

In the Author's previous Paper, attention was drawn to the short life of iron rails on the descending gradient of 1 in 200 on the Great Northern railway between Potters Bar and Hornsey, where iron rails laid in 1860 were worn out in two and a half years. The rails which replaced them in 1863 apparently show better results, inasmuch as they were not taken out until 1870, after enduring the largely increased traffic of the seven subsequent years. In reality, however, this was not the case; for although the rails were guaranteed to last the full term of seven years, the greater portion had to be renewed, at the cost of the manufacturers, long before the guarantee had expired; 28 per cent. only of the rails remained serviceable at the end of the seventh year, so that the average life was only 5·43 years. The same remark applies to the other guaranteed iron rails which still remain on different portions of the main line (Plate 20). It should be mentioned, that the traffic which passed over the portion of the line between Potters Bar and Hornsey, in the period corresponding to this five and a half years' average life, amounted to 34,000,000 tons.

Wherever iron rails still continue in the main line of the Great Northern, they are either on ascending gradients, or just at the departure end of stations, where the speed of the traffic is least.

How entirely the life of the rails is a question of the tonnage, and of the speed and frequency of the trains, may be judged from the fact just mentioned, and from a reference to the renewal diagrams of the Loop and the East Lincolnshire sections of the Great Northern railway (Plate 17), where, owing to the relatively small traffic and easier gradients, the renewals of the permanent way have been slight.

The Loop line, from Walton Junction to Boston, Lincoln, and Gainsborough, was opened for traffic in 1848; the gradients are better, but the amount of traffic is relatively much smaller than on the main line. The earliest renewal of the up line of any serious extent occurred in 1868, or just twenty years subsequent to the opening of the railway; and it has only been within the last year or two since the up line was entirely renewed throughout, partly, it will be observed, with steel rails. On a considerable portion of the down line, however, the original rails, after twenty-eight years' wear, are still in a serviceable condition.

The traffic which passed over these rails from the opening of the line to the end of 1875, has been as follows:—

	Trains.	Tons.
Up line	136,760	39,703,560
Down line	134,186	38,550,980

The East Lincolnshire section of the Great Northern railway extends from Boston to Grimsby. It was opened in 1848, the same year as the Loop; its gradients, however, are not so good, but, on the other hand, the traffic is lighter. The renewals on the up line have amounted to 10 miles, or 21 per cent. of the total up mileage, while the renewals on the down line have only been 2 miles, or about 4 per cent. of the total mileage on the down line. The rails, evidently of a superior make, are for the most part fairly and evenly worn, and have still a considerable amount of wear in them. The traffic over the rails on this line since they were first laid has been estimated as follows:—

	Trains.	Tons.
Up line	67,800	13,400,000
Down line	69,800	14,300,000

The accompanying statement (see next page) of the renewals on the Great Northern railway, in each year during the last ten years, shows that a length of 654½ miles, or 85·1 per cent. of the mileage maintained in 1865, has been entirely renewed in that period, and that the average life of the road is 15·54 years.

The decrease in the average life of the permanent way on the Great Northern, is chiefly attributable, as has been already shown, to the short life of iron rails on certain portions of the main line under the greatly augmented traffic of later years, as well as to the recent more rapid failure of the original iron rails on the Loop and the East Lincolnshire lines.

In 1865 the average life of a mile of single line, as deduced from the system of the Great Northern, was sixteen years. The estimated annual cost of the maintenance and renewal of a mile of single line, where the average life of the rails is sixteen years, and when the average life of sleepers, as on the Great Northern, is eight years, is £128·90, the actual average cost per mile of single line in that year being £134·98.[1]

GREAT NORTHERN RAILWAY. MILEAGE MAINTAINED and MILEAGE RENEWED between the Years 1865 and 1875.

Year.	Miles of Railway maintained. (June half.)	Equivalent Miles of Single Line. (June half.)	Miles of Single Line renewed.	Average Life, Years.
1865	434	769	48	16·02
1866	458	819	50¼	16·50
1867	442	801	56¾	14·12
1868	489	890	73¾	12·07
1869	507	926	62½	14·82
1870	511	930	44½	20·90
1871	511	930	53½	17·38
1872	531½	954½	62¾	15·21
1873	551¼	976½	62¾	15·56
1874	557¾	987½	68½	14·41
1875	558¾	995¼	71¼	13·97
			654½	170·96
				15·54 average.

$$\frac{654\cdot5 \times 100}{769} = 85\cdot1 \text{ per cent.}$$

THE LIFE OF STEEL RAILS.

The first steel rails ever used on a railway were, it is believed, those laid on the London and North-Western in 1862 at Camden Town, and those laid early in the following year in the arrival and departure platform sidings at Crewe station. Rubbings of the latter have been recently taken by Mr. Webb, M. Inst. C.E., who has furnished the Author with drawings, showing the amount of wear, together with the tonnage which has passed over them, from which Plate 18 has been prepared. The wear of some of these rails has varied considerably; the C and D rails, for instance, have been exposed to exactly the same amount of traffic, still while the wear of the tables of the C rails has been 0·875 inch, equivalent to $\frac{1}{16}$ inch for every 5,142,856 tons, that of the D rails has only been 0·531 inch, or per $\frac{1}{16}$ inch wear, 8,474,576 tons. On an average, the Crewe rails required 9,370,777 tons to wear down the heads to the extent of $\frac{1}{16}$ inch. (See next page.)

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[1] Table 3, Appendix.

Tabular Results showing the **Wear** of **Steel Rails.**
Crewe Works, September 30, 1875 (see Table 5, Appendix).

Section.	Original Weight per Yard.	Period in Work.	Estimated Tonnage.	Wear of Tables.	Wear of Tables per Million Tons.	Number of Tons per 1-16th Wear of Tables.
	lbs.	Years.	Tons.	Inch.	Inch.	Tons.
A	75	12	120,000,000	0·625	0·005208	12,000,000
B	"	"	120,000,000	0·625	0·005208	12,000,000
C	"	"	72,000,000	0·875	0·012150	5,142,856
D	"	"	72,000,000	0·531	0·007375	8,474,576
E	"	"	60,000,000	0·406	0·006766	9,236,455
			Average . . .		0·007341	9,370,777

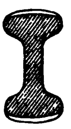
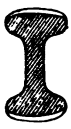
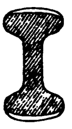
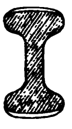
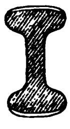
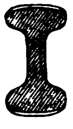
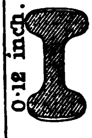
Life of Steel Rails on the Great Northern Railway.

On the Great Northern railway steel rails were first laid in August 1863, at the coal sidings at the King's Cross goods station, where the traffic is particularly heavy. It has been impossible, however, to ascertain the amount of tonnage which has passed over them.

In February 1867 some steel rails were laid in the up and down main lines in Maiden Lane tunnel, at a short distance from the King's Cross passenger station. The traffic over the down-line rails consists almost exclusively of the shunting and marshalling of the trains after their arrival at King's Cross. Although the speed is slow, the traffic is of so incessant a character that the wear of these rails has been more rapid here than on any other part of the line.

With the assistance of Mr. Cockshott, the Superintendent of the line, the Author has been enabled to ascertain the number of engines and vehicles which passed over the rails, and also the amount of traffic over the rails in the adjoining or Copenhagen tunnel, from the time they were first laid to the end of 1875. The worn outline of these rails, the particulars of the tonnage, and the chemical constituents of the steel, are shown on Plate 18, and in Tables 6, 7, and 8, in the Appendix. Here again, as in the Crewe rails, the wear in different rails varies considerably, notwithstanding they have been subjected in several instances to exactly the same amount of traffic. In the case of rail No. 17, Table 6, and Plate 18, for instance, the total wear of the top and bottom tables during a period of nearly nine years has amounted to 0·48 inch under a traffic of 40,329,000 tons (live and dead weight), equivalent to 5,251,000 tons per $\frac{1}{16}$ inch, whereas the wear of the table of rail No. 18, which immediately adjoins it, has only amounted to 0·30 inch, equivalent to 8,402,000 tons per $\frac{1}{16}$ inch. With the view, therefore, of ascertaining, if possible, the cause of this difference in wear, the Author, with the sanction of Mr. R. Johnson, M. Inst. C.E., has obtained from Mr. Riley, analytical chemist, a careful analysis of the material.

SUMMARY of TABLE showing the AMOUNT of WEAR and TONNAGE over STEEL RAILS in and near MAIDEN LANE and COPENHAGEN TUNNELS, together with a CHEMICAL ANALYSIS of the RAILS (See Table 6 in the Appendix, and Plate 18).

	No. 9.	**No. 17.**	**No. 18.**	**No. 21.**	**No. 22.**	**No. 23.**	**No. 24.**
	Copenhagen Tunnel. (Down.)	Maiden Lane Tunnel. (Up.)	Maiden Lane Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)
Total Amount of Wear of both Heads.	0·40 inch. 	0·48 inch. 	0·30 inch. 	0·52 inch. 	0·43 inch. 	0·24 inch. 	0·12 inch. 
	Tonnage.	Tonnage.	Tonnage.	Tonnage.	Tonnage.	Tonnage.	Tonnage.
	96,824,000	40,329,000	40,329,000	63,868,000	63,868,000	59,638,000	59,638,000
	Do. per 1-16th Wear.	Do. per. 1-16th Wear.	Do. per 1-16th Wear.	Do. per 1-16th Wear.	Do. per 1-16th Wear.	Do. per 1-16th Wear.	Do. per 1-16th Wear.
	15,129,000	5,251,000	8,402,000	7,676,000	9,283,000	15,531,000	31,061,000

CHEMICAL ANALYSIS by Mr. RILEY.

Carbon .	0·336	0·331	0·296	0·302	*0·538	0·340	†0·270
Silicium .	0·034	0·029	0·029	0·034	0·040	*0·062	†0·020
Sulphur .	†0·038	0·090	0·051	*0·096	0·059	0·055	0·051
Phosphorus	0·125	0·186	0·144	0·162	0·111	*0·242	†0·100
Iron . .	99·408	99·451	99·637	99·632	99·249	99·223	99·475
Manganese	0·338	0·353	†0·245	†0·245	0·461	*0·475	0·259
Copper. .	*0·032	0·020	0·020	†0·018	0·022	0·028	0·025
	100·311	100·460	100·422	100·489	100·480	100·425	100·200

* Maximum percentage. † Minimum percentage.

The results of Mr. Riley's analysis confirm the statement made by Mr. Smith, in his Paper on Bessemer Steel Rails, viz., "that greater hardness of the material did not conduce to the longevity of steel rails."[1] Thus, in rail No. 17, which shows a large extent of wear, the amount of carbon (0·331) is in excess of that in rail No. 18 (0·296), while the wear of No. 18, viz., 0·30 inch, is less, as has already been shown. In both these rails the silicium appears to be exactly the same. The percentage, however, of sulphur, phosphorus, and manganese is considerably higher in the most worn rail. Rail No. 22, situated on the up line at the north end of the Copenhagen tunnel, has, however, by far the largest proportion of carbon, viz., 0·538 per cent. In this instance the wear has been 0·43 inch under a traffic of 63,868,000 tons (live and dead weight), equivalent to 9,283,000 tons per $\frac{1}{16}$ inch. Immediately adjoining, and subject to nearly the same traffic, is rail No. 24, which, although it has the smallest amount of carbon, viz., 0·270 per cent., shows, at the same time, the least wear, equivalent to 31,061,000 tons per $\frac{1}{16}$ inch. Again, in rail No. 23, which adjoins rail No. 24, the proportion of carbon, 0·340 per cent., is considerably greater, while the wear is almost exactly double that in the last-mentioned rail. In this rail (No. 23) there is a large proportion of phosphorus, manganese, and silicium, and the excess of the latter may possibly account for the increased wear.

The sections showing the extent of wear of the steel rails on other portions of the main line, together with particulars of the tonnage and the results of Mr. Riley's analysis, are given in Plate 18, and Tables 7 and 8, Appendix.

Steel rails were first laid in the running road of the Great Northern in 1866 and 1867, on the up line between the Copenhagen tunnel and Hornsey. Since that time considerable portions of the main line have been renewed with this material. Plate 18, No. 10, represents a section of one of the steel rails laid, in November 1867, at the foot of a gradient of 1 in 200 on the up line near Hornsey, the position of which is marked by a × on the section of the line) Plate 17). This rail has been worn to the extent of only 0·15 inch during nine years and a quarter, and the traffic over it in that time has amounted to 294,359 trains, and 66,546,000 tons (live and dead weight), equivalent to a wear of 27,727,000 tons for every $\frac{1}{16}$ inch, the proportion of carbon being 0·320 per cent. (see Table 7, Appendix).

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 72.

LIFE OF STEEL RAILS ON THE METROPOLITAN RAILWAY.

The Metropolitan railway, between Farringdon Street and Bishop's Road, was opened for traffic in January 1863, and the extension to Moorgate Street in December 1865. The line was originally laid throughout with iron rails, which had, in the course of a short time, to be entirely relaid either with steel-top rails or with steel rails. Most of the rails between Moorgate Street and Bishop's Road have already been worn out (Plate 17) and, in some cases, twice renewed after being subject to a little more than ten years of the enormous and incessant traffic on this railway. Between Farringdon Street and Bishop's Road the renewals have occurred chiefly at or near the different stations. This is attributable, no doubt, to the action of the breaks; moreover, the greatest amount of wear is not where the breaks are first applied, but at a point where they may be supposed to have the maximum effect, intermediate between the place where the breaks are first applied and the station platform. This is particularly noticeable in the renewals of the down road at and near the Edgeware Road station.

With regard to the second renewals between Moorgate Street and Farringdon Street, it should be explained, that these were not necessitated by the rails being worn out, but in order to secure a reserve for repairs on other parts of the line where flange rails are still in use, the double-headed section of rail having recently been substituted for the flange rail by the Metropolitan Company.

Sections of worn rails in the Clerkenwell tunnel are shown on Plate 18. The difference between the wear exhibited by the two sections is attributable, in some measure, to the fact that the one which was most worn was in a wet place, whereas the other rail was in a dry part of the tunnel.

HAMMERING AND COGGING INGOTS.

In Mr. Hackney's Paper on Steel,[1] the process of hammering the ingot is recommended in preference to first 'cogging' it, and then rolling it direct into the finished rail; his objection to 'cogging' being, "that the tearing action of the rolls injures the metal in its unwrought state, making it loose in texture, and often causing cracks in the surface, while the direct blows of a hammer consolidate and toughen it, and do not tend to crack it." With a view of practically testing the relative merits of cogging and hammering, the Author, with the co-operation of Mr Samuel Fox, of the Stocksbridge Works, and of Mr. George Wilson, of the Cyclops Works, at Sheffield, had some rails, made from hammered and cogged ingots respectively, tested at Mr. Kirkaldy's works. Both the hammered and the cogged ingots were obtained from the same Bessemer 'blow.' The results (Plate 19) show conclusively that, so far as strength is concerned, the rail rolled direct from the cogged ingot has decidedly the advantage. The average "ultimate stress" of the rails, on 5-feet bearings, made out of the hammered ingot, was 84,492 lbs., whereas that of the cogged rails was 86,482 lbs., showing 2½ per cent. in favour of the latter. As regards wearing qualities, the steel rails, made from cogged ingots, which were laid on the Great Northern railway in 1866, might be referred to; these rails, after ten years' endurance of the heaviest traffic on that railway, being still in a serviceable condition.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 42.

The Author thinks it due to Mr. Fox to state, that from the first he objected to the process of hammering, as being prejudicial, and that he has throughout consistently declined to manufacture rails from hammered ingots.

FISH PLATES.

Recent experiments by the Author at Mr. Kirkaldy's, show the relative strength of the fished ends of the rail as compared with that of the solid part of the rail (Plate 19). The average ultimate stress of four pieces of solid rail, placed between bearings 5 feet apart, was 73,345 lbs.; while in the case of the deep fish plates of the form shown in section in Plate 19, the "ultimate stress" varied from 48,932 lbs., to 47,764 lbs., representing about 66 per cent. of the strength of the solid rail, whereas the average breaking weight of the ordinary fish plates was only 22 per cent. In one instance failure of a deep fish plate took place through the fracture of one of the bolts. In another through the breaking of the web of both rails through the bolt-holes, as well as through the fracture of one of the fish plates.

DRILLING AND PUNCHING STEEL RAILS.

The weakening effect attributable to punching steel rails has of late been frequently alluded to. With a view of practically ascertaining the loss of strength due to this cause, the Author has carried out a series of experiments at Mr. Kirkaldy's, the results of which are given in Plates 19 and 20. These refer to the transverse strength with 5-feet bearings of—

1. Pieces of 24-feet steel rails in their ordinary state.
2. Pieces of the same rails with four holes punched at the middle of the rails, at the usual distances apart, for the fish plates.
3. Pieces of the same rail with four holes punched to within $\frac{1}{8}$ inch of the full size of the bolt-hole, the remaining $\frac{1}{8}$ inch being drilled out.
4. Pieces of the same rails with four holes drilled to the full size.
5. Pieces of a 24-feet rail which, after being heated to a red heat and plunged in water, were drilled, partly drilled and punched, and punched.

SUMMARY of Mr. KIRKALDY'S REPORTS C and D (*vide* Plate 19).

Rails heated, and afterwards plunged in water.

—	Stress.				Deflection.				Remarks.
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.	
Rails without holes.	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.	
G (cogged)	29,800	..	53,940	..	0·22	..	4·41	..	Snapped.
E do.	27,600	..	49,740	..	0·32	..	4·44	..	Do.
F (hammered)	26,500	..	46,055	..	0·42	..	10·00	..	Unbroken.
H do.	25,700	..	41,745	..	0·76	..	10·00	..	Do.
Mean	27,400	100·0	47,870	100·0	0·43	100·0	7·21	100·0	
Rails with drilled holes.									
H (hammered)	29,300	..	51,705	..	0·61	..	7·24	..	Snapped.
G (cogged)	25,800	..	45,295	..	0·93	..	10·00	..	Unbroken.
E do.	24,500	..	42,725	..	0·97	..	8·30	..	Snapped.
F (hammered)	24,400	..	42,680	..	1·10	..	10·00	..	Unbroken.
Mean	26,500	94·89	45,601	95·26	0·90	209·30	8·88	123·16	
Rails with punched and drilled holes.									
G (cogged)	28,500	..	49,385	..	0·68	..	8·47	..	Snapped.
H (hammered)	27,900	..	46,420	..	0·72	..	10·00	..	Unbroken.
F do.	27,200	..	43,795	..	0·75	..	10·00	..	Do.
E (cogged)	25,800	..	41,520	..	1·28	..	9·58	..	Snapped.
Mean	27,350	99·82	45,280	94·59	0·86	200·00	9·51	131·90	
Rails with punched holes.									
H (hammered)	29,600	..	48,435	..	0·57	..	6·97	..	Snapped.
G (cogged)	26,500	..	45,340	..	0·81	..	6·84	..	Do.
E do.	29,000	..	39,835	..	0·60	..	1·36	..	Do.
F (hammered)	24,700	..	27,570	..	..	..	0·75	..	Do.
Mean	27,450	100·18	40,295	84·18	0·66	153·49	3·98	55·20	

SUMMARY of Mr. KIRKALDY'S REPORTS C and D (*vide* Plate 19)—*continued.*

Rails in ordinary condition.

—	Stress.				Deflection.				Remarks.
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.	
Rails without holes.	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.	
D (hammered)	25,800	..	39,490	..	1·24	..	10·0	..	Unbroken.
B do.	25,100	..	39,410	..	1·32	..	10·0	..	Do.
C (cogged)	24,600	..	38,425	..	1·42	..	10·0	..	Do.
A do.	24,200	..	37,385	..	1·50	..	10·0	..	Do.
Mean . . .	24,925	100·0	38,677	100·0	1·37	100·0	10·0	100·0	
Rails with drilled holes.									
D (hammered)	24,200	..	38,940	..	1·40	..	10·0	..	Unbroken.
B do.	24,000	..	38,840	..	1·42	..	10·0	..	Do.
C (cogged)	23,300	..	38,245	..	1·50	..	10·0	..	Do.
A do.	22,800	..	36,645	..	2·06	..	10·0	..	Do.
Mean . . .	23,575	94·58	38,167	98·68	1·59	116·06	10·0	100·0	
Rails with punched and drilled holes.									
C (cogged)	23,700	..	38,620	..	1·61	..	10·0	..	Unbroken.
B (hammered)	22,200	..	38,095	..	1·65	..	9·72	..	Snapped.
D do.	22,500	..	37,698	..	1·69	..	10·0	..	Unbroken.
A (cogged)	23,800	..	36,890	..	1·75	..	10·0	..	Do.
Mean . . .	23,050	92·48	37,826	97·80	1·67	121·90	9·93	99·30	
Rails with punched holes.									
C (cogged)	22,700	..	26,060	..	..	..	0·61	..	Snapped.
D (hammered)	21,600	..	25,665	..	..	..	0·56	..	Do.
B do.	21,800	..	25,205	..	..	..	0·52	..	Do.
A (cogged)	21,900	..	24,230	..	..	..	0·47	..	Do.
Mean . . .	22,000	88·27	25,290	65·39	..	..	0·54	5·60	

SUMMARY of RESULTS on PREVIOUS PAGES.

—	Stress.				Deflection.			
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.
	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.
Rails heated and cooled in water (without holes) . . .	27,400	109·93	47,870	123·77	0·43	100·00	7·21	100·00
Do. in ordinary condition do. . . .	24,925	100·00	38,677	100·00	1·37	318·60	10·00	138·69
Rails heated and cooled in water (with drilled holes) . .	26,500	110·29	45,601	119·48	0·90	100·00	8·88	100·00
Do. in ordinary condition do. . .	23,575	100·00	38,167	100·00	1·59	176·67	10·00	112·61
Rails heated and cooled in water (with drilled and punched holes)	27,350	118·66	45,280	119·71	0·86	100·00	9·51	100·00
Do. in ordinary condition do. . .	23,050	100·00	37,826	100·00	1·67	194·19	9·93	104·42
Rails heated and cooled in water (with punched holes) .	27,450	124·77	40,295	159·33	0·66	. .	3·98	710·71
Do. in ordinary condition do. .	22,000	100·00	25,290	100·00	. .	. .	0·56	100·00

That drilled, and partly drilled and punched steel rails, are stronger than punched rails, the summary of Reports C and D clearly shows, the ultimate stress of the steel rails punched cold in the ordinary way being 65·39 per cent. of the ultimate stress of the unpunched rails; whereas the ultimate stress of the drilled rails shows 98·68 per cent., and the partly drilled and punched rails 97·80 per cent., of the stress borne by the unpunched rails.

The Author would direct attention to the remarkable results obtained by plunging the rails while hot into water previous to their being drilled or punched. Both the elastic and the ultimate stress of the drilled, the partly drilled and punched, and particularly the punched rails, is increased by being subjected to this toughening process. Thus the ultimate stress of the punched rails is thereby raised to 40,295 lbs., as compared with 25,290 lbs. borne by the rails punched cold in the ordinary way, showing a clear gain of 59·33 per cent. in favour of the toughened rail. But although the ultimate stress borne by the punched rails is much greater after they have undergone this treatment, the advantage gained by it in the case of drilled and the partly drilled and punched rails is relatively much smaller, the ultimate stress of the toughened drilled rails being only 95 per cent. of the stress borne by the toughened undrilled rails; whereas the ultimate stress of the ordinary drilled rails is 98 per cent. of the ordinary undrilled rail. It should further be observed that the amount of deflection and set is much greater in the untoughened steel rails, except when the rails are punched, in which case the untoughened rails show less deflection.

CONCLUSION.

In conclusion, the Author would remark that, although the average wear of steel rails proves them to be superior in durability to iron rails, still it must be admitted that the amount of wear in several instances is much greater than it ought to be with the present knowledge of steel manufacture. It is not, therefore, too much to expect that manufacturers will for the future produce steel rails of such uniform quality, as will at least realise the average maximum endurance already met with in some of the steel rails on the Great Northern railway, viz., 30,000,000 tons per $\frac{1}{16}$ inch wear.

With such a quality of steel, and with a larger quantity of the material placed in the head of the rail, as in the case of the "bull-headed" section, which has, to a great extent, superseded the reversible double-headed rail, a depth of at least $\frac{5}{8}$ inch of the rail-head would be available for wearing purposes. This would give 300,000,000 tons as the average life of a steel rail, as compared with 17,500,000 tons, the ordinary life of iron rails, according to the Great Northern and the Lancashire and Yorkshire experience.[1]

In order fully to realise the effect of such an increase in the enduring quality of steel rails, it may be mentioned that the traffic which during last year passed over the most heavily-worked portion of the Great Northern railway, amounted altogether to 7,110,532 tons, live and dead weight (Table 17, Appendix); consequently the life of steel rails on that portion of the line would be forty-two years, supposing the traffic to remain constant; and the annual cost of the renewals, at present prices, with an average life of forty-two years for the rails and of eight years for the sleepers, would then only amount to £106·60 per mile of single line per annum,[2] instead of £210·09 per mile as at present.[3]

It only remains for the Author to express his obligations to Mr. R. Johnson, for allowing him to exhibit the sectional diagram of the renewals on the Great Northern from the opening of the line up to the present time, together with the diagrams showing the rubbings of the worn steel rails; and for other information relative to the permanent way of the Great Northern railway, which has been largely taken advantage of. His thanks are also due to Mr. Tomlinson, M. Inst. C.E., for the diagram showing the renewals of steel rails on the Metropolitan railway, and for other valuable information. He has at the same time to express his indebtedness to the chief officers of the other railway companies, who kindly furnished information in regard to the cost of maintenance of the permanent way of the railways under their charge.

The communication is accompanied by a series of diagrams, from which Plates 12 to 20 have been compiled.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 362.

[2] Table 15, Appendix.

[3] Table 3, Appendix.

LIST OF DIAGRAMS.

Cost per mile of Maintenance and Renewals of Permanent Way, Works of Line and Station Works on nine of the principal English Railways from 1847 to 1875 . . . . Plates 12, 13, 14
Cost of Maintenance of Way, Cost of Maintenance and Renewals of Points and Crossings and Sidings, and Renewals of Permanent Way and Ballast on the Great Northern Railway, during the last ten years . . . . Plate 15
Sectional Diagrams of the Great Northern Railway, showing the successive Renewals of Permanent Way since the opening of the line . . . . Plate 16
Sectional Diagram of the Metropolitan Railway, showing the Renewals of Permanent Way since the opening of the line . . . . Plate 17
Sections of worn Steel Rails on the Great Northern Railway, referred to in Tables 6, 7, and 8 (App.) . Plate 18
Section of worn Steel Rails on the London and North-Western, Metropolitan, South-Eastern, and Taff Vale Railways, referred to in Tables 5, 9, 10, and 11 (App.) . . . . Plate 18
Results of testing Rails rolled from Cogged and Hammered Ingots . . . . Plate 19
Results of Experiments on Transverse Strength of Fish Plate . . . . Plate 19
Results of Experiments on Rails with Punched and Drilled Bolt-holes, from the works of Messrs. Cammell & Co. . . . . Plate 19
Ditto, ditto, ditto from the works of Messrs. Fox & Co. Plate 20
Actual Rate of Failure of Iron Rails on the Great Northern Railway . . . . Plate 20
Cost, normal Value, and average Money Life of a mile of Permanent Way, taking the average life of sleepers at eight years, and the average life of steel rails at forty-two years . . . . Plate 20

[APPENDIX.

APPENDIX.

Table 1. Increase per cent. of Miles maintained, Gross Receipts, and Tonnage, between December 1864 and December 1874.

„ 2. Increase per cent. of Mileage, and Cost of Maintenance and Renewals during the ten years 1865 to 1875.

„ 3. Cost per Mile of Railway and per Mile of Single Line, during the last ten years, of the various items included under the head of the Maintenance and Renewals of Permanent Way on nine of the principal English Railways.

„ 4. Amount expended in Maintenance and Renewals of Permanent Way, and the amount of Ordinary Capital, on the nine principal English Railways, during the year 1875.

„ 5. Wear, &c., of steel rails on the London and North-Western Railway at Crewe Station.

„ 6, 7, and 8. Wear, &c., of steel rails at the Maiden Lane and Copenhagen tunnels, and on other parts of the Great Northern Railway, together with a chemical analysis of the steel of some of the rails.

„ 9. Wear, &c., of steel rails on the Metropolitan Railway, together with a chemical analysis of the steel.

„ 10. Wear of steel rails on the South-Eastern Railway between London Bridge and Charing Cross stations.

„ 11. Results showing the amount of wear, &c., of steel rails on the Taff Vale Railway.

„ 12, 13, and 14. Experiments on steel rails under bending, pulling, and thrusting stresses, extracted from Mr. Kirkaldy's Reports.

„ 15. Annual cost of renewals of 1 mile of single line, the life of steel rails being forty-two years, and of sleepers eight years.

„ 16 and 17. Tonnage passed over the Great Northern Railway, between Potters Bar and Barnet, from 1865 to 1875 inclusive.

TABLE 1.—INCREASE PER CENT. of MILES MAINTAINED, GROSS RECEIPTS and TONNAGE, BETWEEN DEC. 31, 1864, and DEC. 31, 1874.

Name of Company.	Year ending Dec. 31.	Miles maintained.	Increase per cent.		Gross Receipts.	Increase per cent.		Tonnage.	Increase per cent.	
			In Ten Years.	Per Annum.		In Ten Years.	Per Annum.		In Ten Years.	Per Annum.
		Miles.	Per cent.	Per cnt.	£.	Per cent.	Per cnt.	Tonnage.	Per cent.	Per cent.
London and North-Western . .	1864	1,191	..	..	5,569,117	..	..	12,049,545	..	..
	1874	1,556	30·65	2·71	8,841,711	58·76	4·73	24,017,638	99 33	7·14
North-Eastern	1864	1,095	..	..	3,013,286	..	..	16,234,624	..	..
	1874	1,374½	25·52	2·30	6,241,470	107·13	7·55	32,158,730	98·09	7·08
Midland	1864	663	.	..	2,550,535	..	..	8,849,430	..	..
	1874	1,090¼	64·44	5·10	5,602,498	119·66	8·19	18,876,004	113·30	7·87
London and South-Western . .	1864	505	..	..	1,339,940	..	..	882,205	..	..
	1874	665½	31·78	2·80	2,127,149	58·75	4·73	1,989,642	125·53	8·47
Great Northern	1864	421	..	..	1,757,667	..	..	2,035,269	..	..
	1874	557¾	32·48	2·85	2,763,628	57·23	4·63	5,644,520	177·34	10·74
Lancashire and Yorkshire . . .	1864	381	..	..	1,978,045	..	..	6,109,959	..	..
	1874	396¼	4·00	0·39	3,269,716	65·30	5·16	11,085,086	81·43	6·14
South-Eastern	1864	279	..	..	1,138,968	..	..	690,901	..	..
	1874	337½	20·97	1·92	1,722,637	51·24	4·22	1,184,871	71·49	5·54
London and Brighton	1864	241½	..	..	946,059	..	..	897,736	..	..
	1874	347½	43·89	3·71	1,609,103	70·08	5·46	1,517,541	72·38	5·60
Manchester and Sheffield . . .	1864	242¼	..	..	766,283	..	..	2,537,191	..	..
	1874	259½	7·12	0·69	1,574,984	105·54	7·47	8,094,834	219·05	12·30

TABLE 2.—INCREASE in COST of MAINTENANCE and RENEWALS of PERMANENT WAY DURING the TEN YEARS 1865–1875.

Name of Railway.	Increase per cent. of							
	Cost of Staff.		Wages.		Material.		Total Cost.	
	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
London and North-Western . . .	34·42	36·36	52·56	46·04	81·33	73·47	64·01	65·46
North-Eastern . .	−13·61	−15·11	59·22	57·75	72·69	70·95	71·62	69·89
Midland	47·79	52·97	51·46	51·52	91·95	91·78	63·86	69·87
London and South-Western	53·61	54·52	Not	given	separ	ately.	27·42	25·52
Great Northern . .	−18·54	−19·10	69·56	69·23	50·14	50·18	49·00	48·81
Lancashire and Yorkshire	2·73	2·19	30·55	29·71	48·26	48·83	35·47	34·76
South-Eastern . .	43·14	43·86	−0·15	−2·70	45·93	43·96	1·69	3·54
London, Brighton and South Coast . .	−39·18	−37·10	6·04	6·60	77·18	77·47	34·74	37·20
Manchester, Sheffield and Lincolnshire .	47·35	40·10	34·34	29·84	73·01	69·89	66·68	59·97

included under the head of "Maintenance and Renewals of Permanent Way."

Half Years.	London and North-Western.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	1,215	2,217¾	13·82	7·58	..	..	..	..	202·82	111·12	June 1865.
Dec. "	1,233	2,263¼	13·50	7·36	..	..	..	..	299·62	163·22	Dec. "
June 1866	1,233	2,263¼	15·54	8·46	..	..	..	..	199·63	108·76	June 1866.
Dec. "	1,233	2,303¼	15·16	8·12	..	..	..	..	324·13	173·50	Dec. "
June 1867	1,279	2,334¼	14·76	8·08	..	..	..	..	222·95	122·16	June 1867.
Dec. "	1,325	2,352½	14·36	8·08	..	..	..	..	335·08	188·74	Dec. "
June 1868	1,371	2,399¾	14·07	8·04	..	..	..	..	184·43	105·42	June 1868.
Dec. "	1,416½	2,422¾	13·68	8·00	121·90	71·28	160·44	93·80	296·02	173·06	Dec. "
June 1869	1,423¾	2,424½	14·16	8·32	91·34	53·64	88·54	51·98	194·04	113·94	June 1869.
Dec. "	1,477	2,465¾	14·73	8·82	112·45	67·36	177·60	106·38	304·78	182·56	Dec. "
June 1870	1,481	2,496½	14·76	8·76	86·23	51·16	94·50	56·06	195·49	115·98	June 1870.
Dec. "	1,506½	2,561½	14·26	8·38	131·46	77·32	188·08	110·62	333·80	196·32	Dec. "
June 1871	1,506½	2,559	15·11	8·90	87·35	51·42	88·59	52·16	191·05	112·48	June 1871.
Dec. "	1,514½	2,570½	15·14	8·92	121·83	71·78	205·36	121·00	342·33	201·70	Dec. "
June 1872	1,517	2,595¾	15·94	9·32	126·41	73·88	71·47	41·76	213·82	124·96	June 1872.
Dec. "	1,532½	2,644	15·31	8·88	139·26	80·72	208·86	121·06	363·43	210·66	Dec. "
June 1873	1,537¾	2,666	15·91	9·18	147·96	85·34	123·22	71·08	287·09	165·58	June 1873.
Dec. "	1,556¼	2,715¾	16·50	9·46	163·12	93·48	290·53	166·48	470·15	269·42	Dec. "
June 1874	1,556¼	2,726½	18·64	10·64	151·94	86·72	154·11	87·96	324·69	185·32	June 1874.
Dec. "	1,556¼	2,747	17·72	10·04	160·88	91·14	426·31	241·52	604·91	342·70	Dec. "
June 1875	1,560	2,747	19·00	10·78	154·55	87·68	133·28	75·68	306·83	174·24	June 1875.
Dec. "	1,564½	2,828¾	18·79	10·38	173·83	96·14	376·83	208·42	569·45	314·94	Dec. "
Average	..	..	15·49	8·84	131·37	75·94	185·85	107·06	307·53	175·31[1]	Average.

£. dec.

$$\frac{1,395\cdot67}{175\cdot31} = 7\cdot96 \text{ years' average money life.}$$

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[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	LANCASHIRE AND YORKSHIRE.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£ dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	382	739¼	13·71	7·09	..	..	..	..	431·97	223·21	June 1865.
Dec. „	382	739¼	14·57	7·53	..	..	..	..	298·39	154·19	Dec. „
June 1866	382	739¼	14·91	7·71	..	..	..	..	263·29	136·05	June 1866.
Dec. „	382	739¼	16·86	8·71	..	..	..	..	468·88	242·29	Dec. „
June 1867	382	739¼	13·89	7·18	..	..	..	..	276·16	142·70	June 1867.
Dec. „	383½	742¼	15·01	7·76	..	..	..	..	521·87	269·64	Dec. „
June 1868	383½	742¼	14·85	7·67	..	..	..	..	272·91	141·01	June 1868.
Dec. „	384¾	743½	13·87	7·18	127·99	66·23	451·87	233·84	593·73	307·25	Dec. „
June 1869	384¾	743½	13·97	7·23	121·13	62·68	129·96	67·25	265·06	137·16	June 1869.
Dec. „	390¾	752	13·68	7·11	121·20	62·98	327·45	170·15	462·33	240·23	Dec „
June 1870	390¾	752	14·96	7·77	118·63	61·64	127·96	66·49	261·55	135·90	June 1870.
Dec. „	396¼	758½	14·19	7·41	116·07	60·63	300·00	156·72	430·26	224·77	Dec. „
June 1871	396¼	758½	14·06	7·35	115·07	60·11	126·18	65·92	255·31	133·38	June 1871.
Dec. „	396¼	758½	13·50	7·05	128·96	67·37	319·54	166·93	462·00	241·35	Dec. „
June 1872	396¼	758½	14·65	7·65	131·45	68·67	126·18	65·92	272·28	142·24	June 1872.
Dec. „	396¼	758½	14·96	7·82	136·69	71·41	213·67	111·62	365·32	190·84	Dec. „
June 1873	396¼	758½	15·71	8·21	142·28	74·33	126·18	65·92	284·17	148·45	June 1873.
Dec. „	396¼	758½	15·43	8·06	146·90	76·74	462·32	241·52	624·65	326·32	Dec. „
June 1874	396¼	770¼	14·74	7·58	146·71	75·47	126·18	64·91	287·63	147·97	June 1874.
Dec. „	396¼	770¼	15·83	8·15	139·48	71·76	546·56	281·18	701·87	361·08	Dec. „
June 1875	397¾	773¼	14·74	7·58	164·73	84·73	125·71	64·66	305·18	156·98	June 1875.
Dec. „	437¼	851	13·70	7·04	158·75	81·57	458·34	235·50	630·79	324·10	Dec. „
Average	..	..	14·62	7·58	134·41	69·75	264·54	137·23	397·07	205·78	Average.

[1] £. dec. $\frac{1{,}395\cdot67}{205\cdot78}$ = 6·78 years' average money life.

Half Years.	North-Eastern.										Half Years.
	Mile of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	1,110	1,802¼	15·16	9·34	..	..	..	..	160·22	98·66	June 1865.
Dec. " . . .	1,207¾	1,946¾	14·20	8·80	..	..	..	..	198·68	123·26	Dec. "
June 1866 . . .	1,207¾	1,946¾	15·30	9·50	..	..	..	..	175·88	109·12	June 1866.
Dec. " . . .	1,220¾	1,959¾	14·26	8·88	..	..	..	..	190·58	118·72	Dec. "
June 1867 . . .	1,229	1,978	14·32	8·90	..	..	..	..	109·26	67·88	June 1867.
Dec. " . . .	1,242	2,010	14·32	8·84	..	..	..	..	248·90	153·82	Dec. "
June 1868 . . .	1,246	2,018	13·74	8·48	..	..	..	..	114·96	70·98	June 1868.
Dec. " . . .	1,254	2,029¾	7·26	4·50	84·52	52·22	164·70	101·74	256·48	158·44	Dec. "
June 1869 . . .	1,260	2,041¾	8·48	5·32	75·16	46·38	52·24	32·24	135·88	83·84	June 1869.
Dec. " . . .	1,275	2,071¾	8·94	5·50	85·96	52·90	157·72	97·06	252·62	155·46	Dec. "
June 1870 . . .	1,275	2,071¾	9·58	5·90	77·26	47·54	58·66	36·10	145·50	89·54	June 1870.
Dec. " . . .	1,281¼	2,079	9·54	5·88	94·88	58·48	169·52	104·48	273·94	168·84	Dec. "
June 1871 . . .	1,308¾	2,133½	9·26	5·68	81·82	50·18	55·20	33·86	146·28	89·74	June 1871.
Dec. " . . .	1,314	2,139	10·42	6·40	103·06	63·32	166·56	102·32	280·04	172·04	Dec. "
June 1872 . . .	1,325½	2,162	9·24	5·66	96·32	59·06	61·90	37·96	167·46	102·66	June 1872.
Dec. " . . .	1,329½	2,170	9·94	6·10	120·44	73·80	178·72	109·50	309·10	189·38	Dec. "
June 1873 . . .	1,331	2,173	10·72	6·54	111·70	68·42	90·32	55·32	212·74	130·28	June 1873.
Dec. " . . .	1,332	2,175	11·56	7·08	139·88	85·66	181·20	110·96	332·64	203·70	Dec. "
June 1874 . . .	1,337¼	2,180¼	12·08	7·40	121·48	74·50	131·02	80·36	264·58	162·28	June 1874.
Dec. " . . .	1,379	2,282	12·12	7·32	146·82	88·72	274·18	165·68	433·12	261·72	Dec. "
June 1875 . . .	1,400½	2,304	11·52	7·00	127·22	77·32	141·62	73·92	260·36	158·26	June 1875.
Dec. " . . .	1,400½	2,304	12·16	7·38	154·64	94·00	268·40	163·14	435·20	264·54	Dec. "
Average . . .	..	..	11·55	7·11	108·08	66·17	142·13	86·98	232·01	142·42	Average.

£. dec.

[1] $\frac{1{,}395\cdot 67}{142\cdot 42}$ = 9·80 years' average money life.

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[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	SOUTH-EASTERN.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	286¾	573½	7·58	3·80	..	..	..	..	264·16	132·08	June 1865.
Dec. „ . . .	286¾	573½	5·26	2·64	..	..	..	..	288·22	144·12	Dec. „
June 1866 . . .	286¾	573½	4·63	2·32	..	..	..	..	296·34	148·18	June 1866.
Dec. „ . . .	286¾	573½	6·32	3·16	..	..	..	..	287·06	143·52	Dec. „
June 1867 . . .	286¾	573½	5·48	2·74	..	..	..	..	288·80	144·40	June 1867.
Dec. „ . . .	308½	617	4·99	2·50	..	..	..	..	248·28	124·14	Dec. „
June 1868 . . .	308½	617	6·89	3·44	..	..	..	..	289·35	144·68	June 1868.
Dec. „ . . .	336½	654¼	6·75	3·46	152·53	78·46	83·12	42·76	242·40	124·68	Dec. „
June 1869 . . .	336½	654¼	8·91	4·58	159·40	81·98	84·51	43·46	252·82	130·02	June 1869.
Dec. „ . . .	336½	654¼	7·89	4·06	155·18	79·82	94·17	48·44	257·24	132·32	Dec. „
June 1870 . . .	336½	654¼	6·16	3·18	155·17	79·82	52·63	27·06	213·96	110·06	June 1870.
Dec. „ . . .	336½	654¼	5·25	2·70	149·86	77·08	52·76	27·14	207·87	106·92	Dec. „
June 1871 . . .	336½	654¼	5·95	3·06	146·83	75·52	69·61	35·80	222·39	114·38	June 1871.
Dec. „ . . .	336½	654¼	6·18	3·18	147·80	76·02	66·45	34·18	220·43	113·38	Dec. „
June 1872 . . .	336½	654¼	5·83	3·00	145·46	74·82	59·15	30·42	210·44	108·24	June 1872.
Dec. „ . . .	336½	654¼	6·43	3·30	152·92	78·66	71·94	37·00	231·29	118·96	Dec. „
June 1873 . . .	337½	656¼	5·97	3·08	164·91	84·80	83·96	43·18	254·84	131·06	June 1873.
Dec. „ . . .	337½	656¼	7·70	3·96	153·83	79·10	112·91	58·06	274·44	141·12	Dec. „
June 1874 . . .	337½	656¼	7·32	3·76	148·09	76·16	140·78	72·40	296·19	152·32	June 1874.
Dec. „ . . .	337½	656¼	7·21	3·70	149·30	76·78	115·15	59·22	271·66	139·70	Dec. „
June 1875 . . .	328½	654½	7·90	3·96	154·26	77·42	115·85	58·14	278·01	139·52	June 1875.
Dec. „ . . .	328½	654½	8·90	4·46	157·69	79·14	92·27	46·32	258·86	129·92	Dec. „
Average . . .	..	..	6·61	3·37	152·88	78·37	86·35	40·24	257·05	130·63	Average.

$$^{1}\ \frac{\overset{\text{£. dec.}}{1{,}395\cdot67}}{130\cdot63} = 10\cdot68 \text{ years' average money life.}$$

MIDLAND.

Half Years.	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		Half Years.
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	687¾	1,325¼	10·08	5·24	..	..	..	..	217·96	113·12	June 1865.
Dec. "	687¾	1,325¼	10·60	5·50	..	..	..	..	275·38	142·90	Dec. "
June 1866	742¼	1,393½	9·58	5·10	..	..	..	..	256·28	136·50	June 1866.
Dec. "	742¼	1,393½	8·20	4·36	..	..	..	..	285·62	152·14	Dec. "
June 1867	796¾	1,461¾	9·32	5·08	..	..	..	..	269·00	146·62	June 1867.
Dec. "	796¾	1,461¾	8·54	4·66	..	..	..	..	302·20	164·72	Dec. "
June 1868	864½	1,583½	8·96	4·88	..	..	..	..	251·44	137·28	June 1868.
Dec. "	864½	1,583½	8·54	4·66	113·04	61·72	116·96	63·86	238·56	130·24	Dec. "
June 1869	875¼	1,594¼	9·08	4·98	109·44	60·08	89·90	49·35	208·42	114·42	June 1869.
Dec. "	890¼	1,624¼	10·03	5·50	117·20	64·24	123·38	67·62	250·61	137·36	Dec. "
June 1870	914¾	1,673¼	11·04	6·04	108·14	59·12	97·28	53·18	216·46	118·34	June 1870.
Dec. "	932½	1,703½	11·52	6·31	119·77	65·56	129·83	71·07	261·12	142·94	Dec. "
June 1871	938¾	1,710¾	13·35	7·33	119·11	65·36	125·18	68·69	257·64	141·37	June 1871.
Dec. "	953¼	1,733½	11·97	6·58	135·10	74·29	186·69	102·66	333·76	183·54	Dec. "
June 1872	965½	1,745¾	13·94	7·71	141·34	78·17	145·10	80·25	300·38	166·13	June 1872.
Dec. "	980¼	1,768¾	12·71	7·04	173·26	96·02	175·40	97·21	361·37	200·27	Dec. "
June 1873	1,005¾	1,816¼	15·09	8·36	169·77	94·01	229·16	126·90	414·02	229·26	June 1873.
Dec. "	1,011½	1,847¼	13·16	7·21	191·55	104·89	260·33	142·55	465·04	254·64	Dec. "
June 1874	1,035½	1,887½	15·42	8·46	168·04	92·19	247·12	135·57	430·58	236·22	June 1874.
Dec. "	1,090¼	1,980¼	15·18	8·36	166·83	91·85	221·93	122·19	403·94	222·39	Dec. "
June 1875	1,104¼	2,008½	17·12	9·41	175·27	96·36	225·35	123·90	417·74	229·67	June 1875.
Dec. "	1,106¾	2,025¼	14·80	8·09	186·64	101·99	228·82	125·04	430·26	235·12	Dec. "
Average	..	..	11·74	6·40	146·30	80·39	173·50	95·34	311·26	169·78	Average.

$$\frac{{}^{1}\ \overset{\pounds.\ \ \text{dec.}}{1,395\cdot67}}{169\cdot78} = 8\cdot22 \text{ years' average money life.}$$

800 miles of siding.

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[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	London, Brighton and South Coast.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.[1]		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	241½	451¾	10·50	5·61	..	..	..	..	185·26	99·04	June 1865.
Dec. „ . . .	247½	457¾	10·76	5·90	..	..	..	..	225·68	123·64	Dec. „
June 1866 . . .	247¾	462	11·44	6·13	..	..	..	..	238·60	127·96	June 1866.
Dec. „ . . .	269¾	488½	10·40	5·74	..	..	..	..	252·34	139·34	Dec. „
June 1867 . . .	269¾	488½	10·70	5·91	..	..	..	..	274·44	151·55	June 1867.
Dec. „ . . .	293	529¾	10·68	5·91	..	..	..	..	362·04	200·24	Dec. „
June 1868 . . .	310¾	565¼	11·12	6·11	..	..	..	..	245·64	135·04	June 1868.
Dec. „ . . .	312½	569	10·64	5·84	123·48	67·82	116·06	63·74	250·18	137·40	Dec. „
June 1869 . . .	312½	569	10·62	5·83	118·76	65·22	78·02	42·85	207·40	113·90	June 1869.
Dec. „ . . .	334¾	609¾	6·06	3·33	116·84	64·14	74·56	40·93	197·46	108·40	Dec. „
June 1870 . . .	334¾	609¾	6·32	3·47	130·60	71·70	96·62	53 04	233·54	128·21	June 1870.
Dec. „ . . .	334¾	609¾	6·54	3·59	119·40	65·55	97·36	53·45	223·30	122·59	Dec. „
June 1871 . . .	336¾	613¾	6·58	3·61	121·74	66·80	108·38	59·47	236·70	129·88	June 1871.
Dec. „ . . .	341¾	622	6·50	3·57	118·82	65·28	92·92	51·05	218·24	119·90	Dec. „
June 1872 . . .	346¼	626¼	6·84	3·78	124·08	68·60	64·62	35·73	195·54	108·11	June 1872.
Dec. „ . . .	347½	628¾	6·34	3·50	125·20	69·19	67·56	37·34	199·10	110·03	Dec. „
June 1873 . . .	347½	628¾	6·36	3·52	124·04	68·55	90·82	50·19	221·22	122·26	June 1873.
Dec. „ . . .	347½	628¾	6·20	3·43	117·84	65·13	141·42	78·16	265·46	146·72	Dec. „
June 1874 . . .	347½	628¾	6·00	3·32	124·45	68·78	142·83	78·94	273·28	151·04	June 1874.
Dec. „ . . .	347½	628¾	5·77	3·19	123·98	68·52	128·61	71·08	258·36	142·79	Dec. „
June 1875 . . .	347½	628¾	6·65	3·68	125·54	69·38	132·11	73·01	264·30	146·07	June 1875.
Dec. „ . . .	347½	630½	6·67	3·68	123·77	68·22	106·87	58·90	237·31	130·80	Dec. „
Average . . .	..	..	8·17	4·48	122·57	67·54	102·59	56·52	239·33	131·59	Average.

[1] £. dec.

$$\frac{1,395\cdot 67}{131\cdot 59} = 10\cdot 61 \text{ years' average money life.}$$

200 miles of siding.

TABLE 8—*continued.*

Half Years.	London and South-Western.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	506¾	..	3·36	..	Wages and Materials not given separately in the Reports.				226·66	..	June 1865.
Dec. „ . . .	506¾	..	3·41	..					233·71	..	Dec. „
June 1866 . . .	533½	..	3·26	..					257·50	..	June 1866.
Dec. „ . . .	554½	..	3·42	..					277·04	..	Dec. „
June 1867 . . .	554½	..	3·54	..					243·82	..	June 1867.
Dec. „ . . .	578¾	..	3·56	..					264·50	..	Dec. „
June 1868 . . .	578¾	..	3·62	..					247·70	..	June 1868.
Dec. „ . . .	604	1,027	3·40	2·00					358·14	151·82	Dec. „
June 1869 . . .	604	1,027	3·47	2·04					215·44	126·70	June 1869.
Dec. „ . . .	608	996	3·34	2·04					254·83	155·56	Dec. „
June 1870 . . .	624	1,030	2·98	1·80					198·27	120·12	June 1870.
Dec. „ . . .	624	1,036	3·21	1·94					227·35	136·94	Dec. „
June 1871 . . .	633	1,051	5·31	3·20					191·03	115·06	June 1871.
Dec. „ . . .	633	1,051	4·11	2·48					211·25	127·24	Dec. „
June 1872 . . .	633	1,051	4·55	2·74					213·95	128·86	June 1872.
Dec. „ . . .	640	1,057	4·66	2·82					247·28	149·72	Dec. „
June 1873 . . .	640	1,057	5·26	3·18					259·24	156·96	June 1873.
Dec. „ . . .	646	1,064	5·21	3·16					280·54	170·32	Dec. „
June 1874 . . .	650¾	1,068½	5·29	3·22					313·08	190·68	June 1874.
Dec. „ . . .	665½	1,083¼	5·10	3·14					303·64	186·54	Dec. „
June 1875 . . .	665½	1,094¾	5·25	3·20					259·85	157·96	June 1875.
Dec. „ . . .	674¾	1,104	5·03	3·08					312·33	190·90	Dec. „
Average . . .	..	..	4·11	2·67	..	..	..	..	254·41	151·02	Average.

$$\frac{\overset{\text{£. dec.}}{{}^{1}\,1{,}395\cdot67}}{151\cdot02} = 9\cdot21 \text{ years' average money life.}$$

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[1] Average cost of relaying during ten years.

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TABLE 3—*continued.*

Half Years.	MANCHESTER, SHEFFIELD AND LINCOLNSHIRE.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	242¼	441¾	9·00	4·94	..	..	..	..	191·00	104·74	June 1865.
Dec. „ . . .	246	449¼	9·00	4·93	..	..	..	..	215·00	117·73	Dec. „
June 1866 . . .	246	449¼	10·00	5·48	..	..	..	..	205·00	112·25	June 1866.
Dec. „ . . .	246	449¼	10·00	5·48	..	..	..	..	210·00	114·99	Dec. „
June 1867 . . .	246	449¼	11·00	6·02	..	..	..	..	203·00	111·16	June 1867.
Dec. „ . . .	246	449¼	10·00	5·48	..	..	..	..	197·00	107·87	Dec. „
June 1868 . . .	249	455¼	12·00	6·56	..	..	..	..	182·00	99·55	June 1868.
Dec. „ . . .	258¾	474¾	11·00	6·00	88·00	47·96	115·00	62·68	214·00	116·64	Dec. „
June 1869 . . .	258¾	488	12·00	6·36	87·00	46·13	129·00	68·40	228·00	120·89	June 1869.
Dec. „ . . .	260¾	489½	11·00	5·86	86·00	45·81	140·00	74·58	237·00	126·25	Dec. „
June 1870 . . .	254¼	473½	11·00	5·91	79·00	42·42	151·00	81·08	241·00	129·41	June 1870.
Dec. „ . . .	254¼	473½	10·00	5·31	79·00	42·42	134·00	71·95	223·00	119·68	Dec. „
June 1871 . . .	254¼	473½	13·00	7·20	82·00	43·88	120·00	64·28	215·00	115·36	June 1871.
Dec. „ . . .	257¾	490¼	12·00	6·31	84·00	44·16	144·00	75·71	240·00	126·18	Dec. „
June 1872 . . .	257¾	490¼	13·00	6·83	87·00	45·74	149·00	78·34	249·00	130·91	June 1872.
Dec. „ . . .	257¾	490¼	13·00	6·83	96·00	50·47	223·00	117·24	332·00	174·54	Dec. „
June 1873 . . .	257¾	490¼	13·00	6·83	101·00	53·10	320·00	168·24	434·00	228·17	June 1873.
Dec. „ . . .	258¼	491½	12·00	6·31	108·00	56·75	349·00	183·38	469·00	246·44	Dec. „
June 1874 . . .	258¼	491½	12·99	6·83	110·55	58·09	296·62	155·85	420·16	220·77	June 1874.
Dec. „ . . .	259½	493¼	14·87	7·82	106·86	56·22	287·75	151·39	409·48	215·43	Dec. „
June 1875 . . .	259½	499½	13·27	6·89	113·18	58·80	201·80	104·84	328·25	170·53	June 1875.
Dec. „ . . .	259½	516¾	14·54	7·30	124·84	62·69	186·29	93·55	325·67	163·54	Dec. „
Average . . .	..	..	11·71	6·23	95·50	50·31	196·43	103·44	271·29	144·23	Average.

£. dec.

$$\frac{{}^{1}\,1,395\cdot67}{144\cdot23} = 9\cdot68 \text{ years' average money life.}$$

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[1] Average cost of relaying during ten years.

TABLE 8—*continued.*

Half Years.	GREAT NORTHERN.											Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Miles Relaid.	Staff and Office Charges.		Wages.		Materials.		Total.		
				Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 .	434	769	48	19·88	11·22	70·93	40·02	113·86	64·27	204·67	115·51	June 1865.
Dec. " .	440	781		18·50	10·42	73·83	41·60	181·81	102·43	274·14	154·45	Dec. "
June 1866 .	458	819	50¼	20·24	11·32	67·18	37·56	143·35	80·16	230·77	129·04	June 1866.
Dec. " .	442	801		19·78	10·91	77·68	42·86	176·66	97·48	274·12	151·25	Dec. "
June 1867 .	442	801	56¾	17·74	9·79	73·82	40·74	152·91	84·38	244·47	134·91	June 1867.
Dec. " .	442	801		18·30	10·10	86·94	47·98	155·04	85·55	260·28	143·63	Dec. "
June 1868 .	489	890	73¾	16·90	9·29	103·85	57·06	162·50	89·29	283·25	155·64	June 1868.
Dec. " .	507	926		15·37	8·42	109·88	60·16	173·01	94·71	298·26	163·29	Dec. "
June 1869 .	507	926	62½	14·15	7·75	112·58	61·64	150·30	82·29	277·03	151·68	June 1869.
Dec. " .	511	930		13·69	7·52	109·68	60·27	141·63	77·82	265·00	145·61	Dec. "
June 1870 .	511	930	44½	15·07	8·28	110·83	60·90	127·48	70·05	253·38	139·23	June 1870.
Dec. " .	511	930		15·47	8·50	117·21	64·40	129·90	71·38	262·58	144·28	Dec. "
June 1871 .	511	930	53½	14·94	8·21	115·93	63·70	159·89	87·85	290·76	159·76	June 1871.
Dec. " .	511	930		16·14	8·87	119·74	65·79	141·20	77·58	277·08	152·24	Dec. "
June 1872 .	531½	954½	62¾	14·31	7·97	124·10	69·10	176·34	98·19	314·75	175·26	June 1872.
Dec. " .	540¼	963¼		13·61	7·63	136·98	76·83	162·88	91·35	313·47	175·81	Dec. "
June 1873 .	551¼	976½	62¾	14·23	8·03	129·20	72·94	202·43	114·27	345·86	195·24	June 1873.
Dec. " .	556¾	983½		12·85	7·27	142·73	80·80	246·75	139·69	402·33	227·76	Dec. "
June 1874 .	557¾	987½	68½	14·86	8·39	129·07	72·90	220·41	124·49	364·34	205·78	June 1874.
Dec. " .	557¾	987½		14·28	8·07	134·56	76·00	263·39	148·76	412·23	232·83	Dec. "
June 1875 .	558¾	995¼	71¼	15·30	8·59	130·81	73·44	226·41	127·11	372·52	209·14	June 1875.
Dec. " .	560¾	999¼		15·43	8·66	143·07	80·29	217·58	122·10	376·08	211·05	Dec. "
Average .	..	..	..	15·96	8·87	110·03	61·23	173·89	96·87	299·88	166·97	Average.

£. dec.

[1] $\frac{1,395\cdot67}{166\cdot97}$ = 8·36 years’ average money life.

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[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

AVERAGE COST of RELAYING 1 MILE of SINGLE LINE BETWEEN 1865 and 1875.

Rails' average weight 80 lbs. Price £7 10*s*. per ton.

		Tons.	cwt.		£.	s.	d.		£.	s.	d.
Rails . . .	3,520 yards at 80 lbs. =	126	0	at	7	10	0	=	945	0	0
Chairs . .	4,024 „ 36 „ =	65	0	„	3	15	0	=	243	15	0
Fish plates .	503 pairs „ 24 „ =	5	10	„	7	10	0	=	41	5	0
Bolts	2,012 „ „ 1½ „ =	1	7	„	10	15	0	=	14	10	3
Keys . . .	4,024			„	3	15	0	=	15	1	10
Trenails . .	8,048			„	3	15	0	=	30	3	8
Spikes . .	4,024	1	16	„	9	0	0	=	16	4	0
Sleepers . .	2,012			„	0	3	0	=	301	16	0
Labour . .	1,760 yards . . .			at per yard	0	0	11	=	80	13	4
									1,688	9	1[1]
Renewal of top ballast	1,792 yards			at	0	3	6	=	224	0	0
									1,912	9	1

Credit:—

	Tons.	cwt.		£.	s.	d.		£.	s.	d.	£.	s.	d.
Old rails	105	6	at	3	15	0	=	394	17	6			
„ chairs	37	0	„	2	5	0	=	83	5	0			
Fish plates	4	19	„	6	17	6	=	34	0	8			
Wrought scrap iron . .	1	0	„	4	12	6	=	4	12	6			
											516	15	8
											1,395	13	5

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[1] Cost of materials, ex. labour. £1,608

The normal depreciation in a mile of permanent way would be $\frac{1,608}{3}$ = £536.

pp. 33–36 are bound next to p. 44

TABLE 4.—AMOUNT EXPENDED on MAINTENANCE and RENEWALS of PERMANENT WAY, and the AMOUNT of ORDINARY CAPITAL, for the YEAR 1875, for the NINE UNDERMENTIONED RAILWAYS.

Name of Railway.	Half Year.	Miles of Railway.	Equivalent Miles of Single Line.	Amount expended on Maintenance and Renewals of Permanent Way for the Year 1875.	Amount of Ordinary Capital, 1875.
		Miles.	Miles.	£.	£.
London and North-Western . . .	June	1,560	2,747	239,324	31,126,007
	Dec.	1,564½	2,828¾	445,451	
North-Eastern . .	June	1,400½	2,304	182,308	17,183,124
	Dec.	1,400½	2,304	304,743	
Midland	June	1,104¼	2,008½	230,645	18,800,388
	Dec.	1,106¾	2,025¼	238,101	
London and South-Western . . .	June	665½	1,094¾	86,464	8,220,643
	Dec.	674¾	1,104	105,373	
Great Northern . .	June	558¾	995¼	104,071	9,808,930
	Dec.	560¾	999¼	105,442	
Lancashire and Yorkshire	June	397¾	773¼	60,691	14,116,482
	Dec.	437¼	851	137,909	
South-Eastern . .	June	328½	654½	45,664	7,970,889
	Dec.	328½	654½	42,518	
London and Brighton	June	347½	628¾	45,920	6,839,943
	Dec.	347½	630½	41,232	
Manchester and Sheffield	June	259½	499½	42,590	5,492,553
	Dec.	259½	516¾	42,255	
Total mileage of railway	(June half)	6,622½	11,705½	2,500,701	119,558,959
Average cost per mile per annum			$\frac{2,500,701}{11,705\cdot5}$	=£213·64	

$$\frac{\text{Cost of renewing 1 mile of single line with steel rails £1,626·283}}{\text{Average annual cost of maintenance and renewals \quad 213·64}} = 7\cdot61 \text{ years' average ``money life.''}$$

TABLE 5.—LONDON and NORTH-WESTERN RAILWAY. CREWE STEEL RAILS. (For Sections, see Plate 18.)

—	Section.	Length of Rail.	Original Weight per Yard.	Present Weight per Yard.	Loss of Weight.	When laid down.	When turned.	When taken up.	Period in Work.	Estimated Tonnage.	Wear of Tables.	Number of Tons per $\frac{1}{16}$th Wear of Tables.
		Feet.	lbs.	lbs.	lbs.				Years.		Inch.	Tons.
Steel rails laid in up Main Line south of junction with Crewe Station platform siding	A	24	75	53·56	21·44	1863	1866	1875	12	120,000,000	0·625	12,000,000
	B	24	75	55·43	19·57	1863	1866	1875	12	120,000,000	0·625	12,000,000
Steel rail laid in Crewe Station up platform siding south end . . .	C	21	75	55	20	1863	1866	1875	12	72,000,000	0·875	5,142,856
	D	24	75	55	20	1863	1866	1875	12	72,000,000	0·531	8,474,576
Steel rail laid in Crewe Station up platform siding, opposite south Tank House, March 10, 1863; taken up Oct. 1, 1872; laid down in same place and turned Oct. 30, 1872; re-turned to old face Nov. 21, 1872; again taken up March 17, 1873 (to which date the tonnage is taken) and sent to the Manchester Exhibition; put down to new face Dec. 3, 1873	E	34	75	Not ascertained.		1863	See remarks.		10	60,000,000	0·406	9,370,777

Table 6.—Great Northern Railway. Table showing the amount of Wear and Tonnage over Steel Rails near Maiden Lane and Copenhagen Tunnels, together with a Chemical Analysis of the Rails. (For Sections, see Plate 18.)

—	Copenhagen Tunnel. Down Line.	Maiden Lane Tunnel. Up Line.		North of Copenhagen Tunnel. Up Line.			
	No. 9.	No. 17.	No. 18.	No. 21.	No. 22.	No. 23.	No. 24.
Original weight per yard	75 lbs.	75 lbs.	75 lbs.	75 lbs.	75 lbs.	82 lbs.	82 lbs.
When laid down .	Nov. 1866.	Feb. 1867.	Feb. 1867.	March 1867.	March 1867.	Nov. 1867.	Nov. 1867.
When turned . .	June 1869.	July 1870.	July 1870.	Feb. 1870.	Feb. 1870.	Nov. 1869.	Nov. 1869.
Rubbings taken .	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.
Period in work up to rubbings . .	8 yrs. 10 mths.	8 yrs. 7 mths.	8 yrs. 7 mths.	8 yrs. 6 mths.	8 yrs. 6 mths.	7 yrs. 10 mths.	7 yrs. 10 mths.
Gradients of line .	Rising 1 in 10.	Falling 1 in 105.	Falling 1 in 105.	Falling 1 in 110.	Falling 1 in 110.	Falling 1 in 110.	Falling 1 in 110.
Tonnage passed over	96,824,000	40,329,000	40,329,000	63,868,000	63,868,000	59,638,000	59,638,000
Wear of tables . .	0·40	0·48	0·30	0·52	0·43	0·24	0·12
No. of tons per $\frac{1}{16}$th wear of tables .	15,129,000	5,251,000	8,402,000	7,676,000	9,283,000	15,531,000	31,061,000
Chemical Analysis by Mr. Riley.							
Carbon	0·336	0·331	0·296	0·302	* 0·538	0·340	† 0·270
Silicium	0·034	0·029	0·029	0·034	0·040	* 0·062	† 0·020
Sulphur	† 0·038	0·090	0·051	* 0·096	0·059	0·055	0·051
Phosphorus . . .	0·125	0·186	0·144	0·162	0·111	* 0·242	† 0·100
Iron	99·408	99·451	99·637	99·632	99·249	99·223	99·475
Manganese . . .	0·338	0·353	† 0·245	† 0·245	0·461	* 0·470	0·259
Copper	* 0·032	0·020	0·020	† 0·018	0·022	0·028	0·025
	100·311	100·460	100·422	100·489	100·480	100·425	100·200

Maximum percentage shown thus * Minimum percentage shown thus †

TABLE 7.—GREAT NORTHERN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS, and a CHEMICAL ANALYSIS of the RAILS. (For Sections, see Plate 18.)

—	Between Hornsey and Wood Green. Up Line.	Between Barnet and Potters Bar. Up Line.	South of Potters Bar Station. Down Line.	South of Biggleswade. Up Line.		Through Biggleswade Station. Down Line.	South of Peterborough. Down Line.	North of Doncaster. Up Line.
	No. 10.	No. 22.	No. 24.	No. 64.	No. 55.	No. 66.	No. 84.	No. 6.
Original weight per yard	82 lbs.	..	72 lbs.	80 lbs.	80 lbs.	80 lbs.	80 lbs.	75 lbs.
When laid down .	Nov. 1867.	April 1872.	March 1867.	April 1874.	July 1873.	May 1871.	Feb. and Mar. 1871.	Oct. and Nov. 1865.
When turned . .	Not turned.	Qy. date.	← . . . . Not turned. . . . . →					August 1867.
Rubbings taken .	← . . . . March 1876. . . . . →							
Period in work up to rubbings . .	8 yrs. 4 mths.	3 yrs. 11 mths.	9 years.	1 yr. 11 mths.	2 yrs. 9 mths.	4 yrs. 10 mths.	5 years.	10 yrs. 4 mths.
Gradients of line .	← . . Falling 1 in 200. . . →			← Rising 1 in 330. →		Level.	Falling 1 in 605.	Rising 1 in 400.
Tonnage passed over	66,546,000	28,051,000	33,105,000	..	..	..	..	..
Wear of tables . .	0·15	0·13	0·10	..	..	..	..	..
No. of tons per $\frac{1}{16}$th wear of tables .	27,727,000	13,486,000	20,690,000	..	..	..	..	..
	Chemical Analysis by Mr. Riley.							
Carbon	·320	·285	·319	·349	† ·158	·323	·241	* ·406
Silicium	·037	† ·021	·077	·081	·046	* ·102	·037	·045
Sulphur	·030	† ·029	·031	* ·089	·076	·060	·068	·046
Phosphorus . . .	* ·193	* ·193	·090	·068	·074	·087	† ·064	·079
Iron	99·667	99·905	99·817	99·462	99·719	99·423	99·718	99·617
Manganese . . .	·316	·273	·302	* ·576	† ·187	·446	·367	·359
Copper	* ·026	·029	·033	·033	·039	·033	·028	* ·046
	100·589	100·735	100·669	100·658	100·299	100·474	100·523	100·598
Character of material as found in drilling . . .	Moderately hard.	Very hard.	Very hard.	Soft.	Soft.	Hard.	Very soft.	Moderately hard.

Maximum percentage shown thus * Minimum percentage shown thus †

TABLE 8.—GREAT NORTHERN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS.
(For Sections, see Plate 18.)

—	In Maiden Lane Tunnel, South End.		In Maiden Lane Tunnel, North End.	North of Maiden Lane Tunnel.		Between Maiden Lane and Copenhagen Tunnels.				Between Wood Green and Southgate.	
	Down Line.		Down Line.	Down Line.		Down Line.		Up Line.		Up Line.	
	A.	No. 1.	B.	No. 4.	No. 5.	No. 6.	No. 7.	No. 19.	No. 20.	No. 12.	At Southall Station Platform. No. 14.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Original weight per yard . .	75	75	75	75	75	82	82	82	82	82	82
When laid down .	September 1866.					March 1863.				Feb. and March 1868.	
When turned .	3 times.		Once.	3 times.		Not turned.	Once.			Not turned.	
Rubbings taken .	July 1871.	Aug. 1871.	Dec. 1870.	Mar. 1875.		August 1871.		May 1875.		April 1875.	
Period in work up to rubbings .	4 yrs. 11 mo.	5 yrs.	4 yrs. 3 mo.	8 yrs. 6 mo.		8 years 5 months.		12 yrs. 2 mo.		7 years 2 months.	
Gradients of line.	← . . . . Rising 1 in 105. . . . . →							Falling 1 in 105.		Falling 1 in 200.	
Tonnage passed over. . . .	64,780,000	66,224,000	12,865,000	32,691,000		22,093,000		42,927,000		51,923,000	
Wear of tables .	0·58	0·42	0·32	0·40	0·38	0·11	0·19	0·26	0·25	0·32	0·40
No. of tons per $\frac{1}{16}$th wear of tables .	6,981,000	9,855,000	2,513,000	5,239,000		12,553,000	7,267,000	10,521,000		10,141,000	8,113,000

TABLE 9.—METROPOLITAN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS, and a CHEMICAL ANALYSIS of the RAILS. (For Sections, see Plate 18.)

—	Between Praed Street and Bayswater.		Between Baker Street and Edgeware Road.		Between St. John's Wood Road and Marlborough Road.	Clerkenwell Tunnel.	
	Up Line.	Down Line.	Up Line.	Down Line.	Single Line.	Up Line.	
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6. Dry place.	No. 6a. Wet place.
When laid down .	Oct. 1868.	Oct. 1868.	June 1866.	June 1866.	April 1868.	June 1866.	June 1866.
When taken up. .	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.
Period in work . .	7 years 4 months.		9 years 9 months.		7 yrs. 11 mths.	9 years 9 months.	
Gradients of line .	Rising 1 in 75.	Falling 1 in 75.	Falling 1 in100.	Rising 1 in 100.	1 in 60.	Falling 1 in 500.	
Tonnage passed over	32,086,470	32,086,470	89,105,900	89,105,900	46,623,568	99,889,140	99,889,140
Wear of tables . .	0·27	0·36	0·28	0·35	0·40	0·45	0·93
No. of tons per $\frac{1}{16}$th wear of tables. .	7,427,500	5,570,600	19,890,000	15,912,000	9,713,400	13,874,000	6,713,000
Chemical Analysis by Mr. Riley.							
Carbon	·317	·295	* ·679	† ·294	·316	·405	·423
Silicium	·046	·042	* ·640	·059	† ·026	·031	·046
Sulphur	·037	·040	·040	·037	* ·041	† ·030	·037
Phosphorus . . .	·111	·132	·067	·067	* ·133	† ·060	·087
Iron	99·637	99·587	98·896	99·620	99·756	99·529	99·475
Manganese . . .	·259	·403	* ·533	·310	† ·230	·389	·518
Copper	·032	·040	† ·030	† ·030	·058	* ·059	·052
	100·439	100·593	100·885	100·417	100·560	100·503	100·638

Maximum percentage shown thus * Minimum percentage shown thus †

Table 10.—South-Eastern Railway. Wear of Steel Rails between London Bridge and Charing Cross Stations.
(For Sections, see Plate 18.)

—	Supplied by		
	The Railway Steel and Plant Company.	Ebbw Vale Company.	Landore Siemens Steel Co. (Limited).
	No. 1.	No. 2.	No. 3.
When laid down	August 1868.	August 1869.	April 1872.
Rubbings taken	Oct. 1875.	Oct. 1875.	Oct. 1875.
Period in work	7 yrs. 2 mths.	6 yrs. 2 mths.	3 yrs. 6 mths.
Tonnage passed over . . .	30,786,000	37,228,000	31,394,000
Wear of top table	0·45	0·60	0·125
No. of tons per $\frac{1}{16}$th wear of tables	4,276,000	3,878,000	15,697,000

Table 11.—Taff Vale Railway. Wear of Steel Rails.
(For Section, see Plate 18.)

—	Supplied by Messrs. J. Brown and Co., Sheffield.
When laid down	August 1863.
Rubbing taken	April 30, 1876.
Period in work	12 yrs. 8 months.
Tonnage passed over	63,289,000
Wear of tables	0·125
No. of tons per $\frac{1}{16}$th wear of tables . .	31,644,000

Table 15.—Annual Cost of Renewals of 1 mile of Single Line of Railway w Steel Rails (Credit being allowed for old materials). The Life of Steel Rails be Forty-two Years, Sleepers Eight Years.

No.	Description.				—			Net Cost.			Life in Years.	Net Co per Ann	
		£.	s.	d.	£.	s.	d.	£.	s.	d.		£.	s.
503	Steel rails, 21 ft., 3,521 yds. at 80 lbs. = 126 tons, at.	10	0	0	1,260	0	0						
	Do., credit, 3,520 yds. at 78 lbs. = 123 tons, at .	3	15	0	461	5	0	798	15	0	42	19	0
4,024	Chairs, 40 lbs. = 72 tons, at	4	10	0	324	0	0						
4,000	Credit old chairs, 28 lbs. = 50 tons, at.	2	5	0	112	10	0	211	10	0	42	5	0
Pairs. 503	Fish plates, 40 lbs. = 9 tons, at	8	15	0	78	15	0						
503	Do., credit old, 22 lbs. = 4 tons 19 cwt., at . .	4	10	0	22	·5	0	56	9	6	15	3	15
2,012	Fish bolts, 1½ lbs. each = 1 ton 7 cwt., at . . .	17	0	0	22	19	0						
	Credit old scrap, 1 ton, at .	3	15	0	3	15	0	19	4	0	10	1	18
4,024	6-inch keys, at	3	15	0	15	1	10	15	1	10	3	5	0
8,048	Treenails, at	3	15	0	30	3	8	30	3	8	3	10	1
4,024	Spikes, 1 lb. each = 1 ton 16 cwt., at	14	0	0	25	4	0						
	Do., credit old scrap, 1 ton, at	3	15	0	3	15	0	21	9	0	6	3	11
2,012	Sleepers, each at . . .	0	3	11	385	12	8	385	12	8	8	48	4
	Labour, 1,760 yards at. .	0	1	0	88	0	0	88	0	0	16	5	10
								1,626	5	8		102	2
C. yds. 1,792	Ballast (top ballast), at, including labour . . . = 11′ 0″ × 5,280 × 0′ 10″	0	2	6	224	0	0	224	0	0	[1] 50	4	9
								1,850	0	0		106	11

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[1] Note.—The average annual cost of Ballast for Maintenance and Renewals of the Permanent Way du the last ten years was exactly £6·51 per mile of single line. Labour is taken at the mean of the lives of different materials.

ESTED under BENDING STRESS, per REPORTS A, C, D, and F.

nat er are ch.	t No.	Thrusting Stress.				
		Cut out of Rail Top.				
		Stress.	Depression. Set, 1 inch.			Appearance of Surface.
		Elastic per Square Inch.	At 50,000 lbs. per Square Inch.	At 100,000 lbs. per Square Inch.	At 150,000 lbs. per Square Inch.	
s.	K.	lbs.	Per cent.	Per cent.	Per cent.	
98	,024	58,000	0·0	3·3	13·9	Very slightly marked.
94	,027	58,000	0·0	3·5	14·1	Do.
46		58,000	0·0	3·4	14·0	Very slightly marked.
70	,018	55,500	0·0	3·8	15·4	Very slightly marked.
05	,021	55,000	0·0	4·1	16·3	Do.
87		55,250	0·0	3·9	15·8	Very slightly marked.
22	,428	66,000	0·0	3·4	15·6	Very slightly marked.
72	,422	61,500	0·0	6·1	20·2	Do.
08	,425	57,000	0·0	7·0	21·8	Do.
98	,431	51,500	0·0	9·9	24·4	Do.
75		59,000	0·0	6·6	20·5	Very slightly marked.
,6	410	51,000	0·0	9·1	24·5	Very slightly marked.
,0	413	49,000	0·3	9·3	25·1	Do.
,0	416	49,000	0·3	9·3	25·1	Do.
,0	419	48,000	0·5	9·8	25·2	Do.
,2		49,250	0·3	9·4	25·0	Very slightly marked.
,1	667	54,000	0·0	5·1	18·8	Very slightly marked.
,2	670	54,000	0·0	5·1	18·8	Do.
,6		54,000	0·0	5·1	18·8	Very slightly marked.

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Table 17.—Number and Gross Weight of Trains passing over the Up Line of the Great Northern Railway between Barnet and Potters Bar, 1865 to 1875.

Year.	Trains.	Number.	Weight.	Total of all Trains per Annum.	
				Number.	Weight.
		No	Tons.	No.	Tons.
1865	Passenger.	10,062	1,354,864	24,440	5,668,264
	Goods . .	14,378	4,313,400		
1866	Passenger.	12,532	1,686,672	26,598	5,906,472
	Goods . .	14,066	4,219,800		
1867	Passenger.	12.376	1,666,236	26,078	5,776,836
	Goods . .	13,702	4,110,600		
1868	Passenger.	10,894	1,466.010	23,946	6,034,210
	Goods . .	13,052	4,568,200		
1869	Passenger.	10,010	1,346,202	21,034	5,204,602
	Goods . .	11,024	3,858,400		
1870	Passenger.	9,412	1,266,460	21,970	5,661,760
	Goods . .	12,558	4,395,300		
1871	Passenger.	9,386	1,262,808	22,386	5,812,808
	Goods . .	13,000	4,550,000		
1872	Passenger.	9,724	1,308,060	23,608	6,861,660
	Goods . .	13,884	5,553,600		
1873	Passenger.	10,088	1,357,616	24,180	6,994,416
	Goods . .	14,092	5,636,800		
1874	Passenger.	10,530	1,416,984	24,544	7,022,584
	Goods . .	14,014	5,605,600		
1875	Passenger.	11,570	1,556,932	25,454	7,110,532
	Goods . .	13,884	5,553,600		
				264,238	68,054,144

Mr. R. PRICE WILLIAMS said since the Paper was written he had completed some additional experiments, at Mr. Kirkaldy's works, on the tensile and compressive strength of rails rolled from cogged and from hammered ingots, and also on steel rails which, previous to being punched, had been plunged, while hot, into water; and the results fully confirmed those previously given by the bending stress. The results of these later experiments showed that the limit of elasticity under the pulling stress was more than 12 per cent. higher in the cogged than in the hammered ingot rails, and that the limit of elasticity under thrusting stress was 5 per cent. in favour of the cogged ingot rails. Further, there were indications of greater toughness in the cogged ingot rails under the thrusting stress, the depression under weights of 100,000 lbs., and 150,000 lbs. per square inch, being 13 per cent. less.

SUMMARY of TABLE 12 (*vide* Appendix),
Messrs. Fox and Co.'s STEEL RAILS.

Pulling Stress.

—	Elastic Stress per square inch.		Ultimate Stress per square inch.		Ultimate Extension per cent. of length.	
	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.
	lbs.	lbs.	lbs.	lbs.		
Rails made from cogged ingots	52,400	52,750	95,476	99,805	7·9	9·2
Rails made from hammered ingots	46,650	48,950	100,878	101,695	15·8	15·4
Percentage in favour of cogged ingot . .	12·33	7·76	..	..	..	..

Thrusting Stress.

—	Elastic Stress.	Percentage in favour of Cogged Ingots.	Depression at 100,000 lbs. per square inch per cent.	Depression at 150,000 lbs. per sq. inch per cent.
	lbs.			
Rails made from cogged ingots . (Rail top.)	58,000	4·97	3·4	14·0
Rails made from hammered ingots (Rail top.)	55,250		3·9	15·8

As regarded the steel rails, marked E, F, G, H on Plate 19, which before being punched had been quenched in water, the experiments showed that the limit of their elasticity under pulling stress was far higher when thus treated, the elasticity of the steel taken from the head of these rails being, on an average, 17·61 per cent. greater. The increased toughness resulting from this particular treatment of the material was, moreover, strikingly shown by the results obtained under the thrusting stress, the limit of elasticity of the rails plunged while hot into water being 59,000 lbs. per square inch, as compared with 49,250 lbs. in the case of the untoughened rails, or about 20 per cent. in favour of the former. Again, the same favourable results were shown by the much smaller amount of the depression of the toughened rails under thrusting stress, the depression amounting only to 6·6 per cent. under a pressure of 100,000 lbs. per square inch, as compared with 9·4 per cent. in the rail which had not been so treated, showing 42·42 per cent. in favour of the material which had undergone this toughening process.

The average amount of carbon in all the steel rails of Messrs. Cammell and Co. was only ·174 per cent. for the A, B, C, and D rails, and ·179 per cent. in the case of the E, F, G, and H rails.

SUMMARY of TABLE 12—*continued* (*vide* Appendix),
Messrs. CAMMELL and Co.'s STEEL RAILS.

Pulling Stress.

—	Portions from Rail Top.				Portions from Flange.			
	Elastic Stress.		Ultimate Stress.		Elastic Stress.		Ultimate Stress.	
	lbs.	Per cent.[1]	lbs.	Per cent.[1]	lbs.	Per cent.[1]	lbs.	Per cent.[1]
Rails plunged when hot into water . (G, E, F, H.)	48,075	17·61	90,750	11·72	53,250	16·08	92,555	13·78
Rails in ordinary state . . . . (A, B, C, D.)	40,875		81,225		45,875		81,342	

Thrusting Stress.

—	Elastic Stress.		Depression under 100,000 lbs. per square inch per cent.		Depression under 150,000 lbs. per square inch per cent.	
	lbs.	Per cent.[1]		Per cent.[1]		Per cent.[1]
Rails plunged when hot into water . (G, E, F, H.)	59,000	19·80	6·6	42·42	20·5	21·95
Rails in ordinary state . . . . (A, B, C, D.)	49,250		9·4		25·0	

[1] In favour of cooled rails.

In the course of the discussion on his former Paper on Rolling Stock, exception had been taken to the average rate of depreciation assumed in the case of locomotive engines, which increased, according to his view, as the square of the time; his contention being, that while the rate of depreciation of some of the longest lived parts of the structure was tolerably uniform, many other parts were exposed to constant wear, where the rate of depreciation must necessarily be much more rapid, being probably as the cube of the time; but that the average rate of depreciation of all the parts would be a mean between these two extreme cases, a condition fulfilled by the ordinary parabolic curve. The means of practically testing the rate of depreciation of iron rails had, since then, fortunately presented itself, and he had been enabled, through the kindness of Mr. Johnson, M. Inst. C.E., Chief Engineer of the Great Northern Railway Company, to exhibit diagrams, Plate 20, showing the actual failures of guaranteed rails, and extending over periods of seven years. It would be observed, that the outline, showing the rate of failure of the rails of the 4,000 tons contract, Fig. 1, almost exactly coincided with his curve of average depreciation, which increased as the square of the time. The figures No. 2 and 3 showed the rates of failure in the other two contracts for guaranteed rails of 1,600 tons and 1,400 tons respectively. The curves in these cases indicated a depreciation increasing in a somewhat higher ratio than that of the square of the time. This afforded a strong confirmation of his view, that in all structures composed of different parts, and subject to wear, the curve of depreciation must necessarily be of the character described. Following out that idea, he exhibited a diagram (Plate 20), showing the value of 1 mile of permanent way, at successive periods, assuming the depreciation to increase as the square of the time, and the life of steel rails to be forty-two years. In this diagram the serrated outline showed the net value of the permanent way, before and after each renewal of the different parts. The curved line of average depreciation gave an exact average of the irregular serrated outline, and its mean ordinate occurred at about twenty years, or, in exact figures, at ·577 of the longest life—at which period the permanent way would have attained its average value, viz., two-thirds of the first net cost, to which, of course, for purposes of valuation, would have to be added the scrap value of the materials. It consequently followed that the normal depreciation in 1 mile of permanent way was one-third of its first net cost.

With regard to the tests of the fish-plates, it would be seen that the bearings were 5 feet apart, and that the results were relative.

Mr. Kirkaldy had declined to test the rails with 2-feet bearings, thinking, and he thought correctly, that with bearings 2 feet apart it was impossible to get any useful result as to deflection or set: nor was it fair to consider rigid supports 2 feet apart as at all comparable with sleepers 2 feet apart. He was glad of the opportunity of expressing his obligations to Mr. Kirkaldy for the great assistance afforded him, apart from business considerations, throughout this inquiry.

Mr. MAY said a cogged ingot was, in truth, simply the reduction of an ingot to the size of the bloom—say from 12 inches to 6½ inches square. Whether done with a hammer or by rolls it was still cogging. The only difference between rolling or hammering an ingot down to the bloom was that, in hammering, the result was an ingot with a rounded end, on account of the percussive force driving out the soft metal towards the end; and in the other case a bird's-mouth ingot, by drawing the metal over; the tensile strength and wearing properties were the same, whether the reduction was effected by hammering or by rolling. He did not understand what was meant by toughening by plunging into water. Steel with a sufficient amount of carbon was hardened by plunging into water; with less carbon it was made more resistant, but not tougher. As to punching and drilling, there was no difference in the results, except that in the punched rail there was sometimes a minute crack at the end which came out in the wear. Punching or drilling did not affect the actual strength of the rail.

Mr. W. B. LEWIS felt under great obligation to Mr. Price Williams for the mass of information he had collected, to which it seemed hopeless to attempt to add anything. But on one or two points he thought there was not material enough to form an accurate opinion. He had studied the table of analyses with great interest, but without much satisfaction. With reference to carbon, which was usually regarded as most important in the composition of steel, it was true that a rail with a minimum of carbon showed the best result. With rails 17 and 18 at the Maiden Lane tunnel the minimum of carbon showed the better result, but with the next two rails from Copenhagen tunnel, the circumstances being the same, the maximum of carbon gave the better result. Looking at the table, the only thing that seemed evident was, that the rail with the smallest amount of phosphorus was the best, and there seemed to be a pretty regular progression. He believed some engineers had lately inserted in their specifications the chemical test for steel and iron rails. With regard to the question of punching he felt compelled to differ from Mr. May. His own experience was that the effect of punching a steel rail was to weaken it. The material was brittle, and if in punching any little fractures were produced, however minute, even if hardly discoverable by the microscope, they were liable to increase; and with the jar and concussion to which rails were subjected mischief might be done. But drilling he had found to be a very serious matter. In the case of a large order for rails from the Barrow Company, drilling oval holes had been insisted upon; and the Company put up several machines made by Messrs. Sharp, Stewart, and Co., for the purpose; but all sorts of practical difficulties arose. The machines were so arranged that two rails were brought together and two holes in each rail were drilled at the same time, and it sometimes took eighteen minutes to get through the four holes. The order being for 6,000 tons, they were alarmed at the idea of spending so much time over the operation of drilling. It was also found that the skin of the rail differed so greatly, that where one tool would enter freely the next would be turned, and the tools would not travel at the same pace. All those difficulties were, however, surmounted by adopting the plan which Mr. Williams had described, viz., punching a small hole first, through which a cutting tool could be put, taking a centre on the other side, and then cutting an oval hole, or rather an elongated hole with two round ends. The rule adopted was that every hole should have at least $\frac{1}{8}$ inch cut away by the cutting tool. Again, with regard to cogging and hammering, he could not help thinking that sufficient information had not been obtained. The Author had supplemented the Paper by additional remarks on this subject, but in the Paper itself there was not enough to justify the conclusion, that the one plan was better than the other. Engineers in charge of the maintenance of way state that they had no occasion to complain of the fish-plates, and that they saw no reason for incurring the expense of deeper ones. It appeared that the fish-plate in Fig. 22 broke the rail. It was manifest that there was more iron in it than was needed. The joint was said to be 66 per cent. of the strength of the solid rail. By adopting the customary plan of reducing the bearings to 2 feet at the joint instead of 3 feet elsewhere, there would be a gain to nearly the extent of the loss thus indicated, and the joint would be as strong as the rest of the rail. The result seemed to point to there being too much material in the fish-plate. Looking at the section adopted on the Metropolitan railway, it appeared that neither the fish-plate nor the rail gave way, but the bolt. That seemed to betray a bad-fitting fish-plate. He did not think that the ultimate strength of the joint was that which it was needful to ascertain, but the stiffness; so that one rail should not deflect before the other. His opinion had always been, that a fish-plate should be so made that no sheer could come on the bolts, but that their work should be limited to holding the two cheeks together. In the case in point it appeared that the bolt was doing work that ought not to be required of it. If the shoulder of the plate had been made to fit under the rail, either the rail or the plate must have gone before the bolt, or the thread must have stripped. He hoped to hear whether the plate in common use, when well made and fitted, was found in practice to be unequal to its work.

Mr. **Langley** said, in 1874 he laid down some permanent way near Stepney on the Blackwall branch of the Great Eastern railway, where there were upwards of three hundred trains a day passing over a single line. The weight of each train was, on an average, about 150 tons, making a total of about 45,000 tons daily over one line of rails. The permanent way on this length was composed of both steel and iron rails (from nearly all the principal manufacturers in England), weighing 80 lbs. to the yard, and keyed in cast-iron chairs resting on rectangular sleepers. The steel and iron were purposely laid close together so as to be under precisely similar conditions of wear and tear. The greater number of the wrought-iron rails had to be turned in one year and three-quarters, during which period they had worn down about $\frac{1}{8}$ inch; but they had not to be turned on account of this wear, but because they gave way in places either by bulging or by splitting. The steel rails had worn about $\frac{1}{16}$ inch in one year and three-quarters, after about 27 million tons had passed over them; which was rather in excess of the figures given by Mr. Williams. The fact of the wrought-iron rails wearing away twice as much as the steel was not an indication of the true value of the two metals; because the steel rails after wearing down $\frac{1}{16}$ inch were still available, and would continue to be so until nearly the whole of the head was worn off, the wearing down being regular and uniform. The iron rails, on the other hand, were crushed in places and no longer fit to remain in the road. He had found that the old rails were far more durable than the new ones now supplied by manufacturers. The latter were like a bundle of fagots not tied properly together, and always gave way either by bulging or by splitting; in fact, their life was most uncertain, while the old rails wore down more like steel rails. He had invariably put the sleepers about 2 feet apart at the joints, increasing the distance to about 3 feet in the centre of the rail. This being done, and with the ordinary fish-plate properly screwed up, the joints could not be felt, and a continuous elastic line of rails was obtained.

In February 1873, at the Nine Elms goods-yard on the London and South-Western railway, he had laid a steel rail on one side and an iron rail on the other side of the shunting road where there was most traffic, an average of nearly four hundred engines and trains passing over this line in the twenty-four hours. The steel rail at the present time was in good condition, a layer of $\frac{3}{16}$ inch being worn off; while during the same period, over three years, on the opposite side the iron rail had been renewed three times, the renewal taking place after each rail had been turned, and both heads so worn that the rail was unfit to remain.

It was curious to notice the difference of opinion amongst Engineers as to the best form of rail section. On the Continent and in America, Engineers had almost invariably used the flat-footed rail; and he noticed last week that, on some of the western lines in France, rails keyed in chairs were being replaced by flat-footed rails. On the Metropolitan line, on the contrary, the flat-footed rail was being taken up and the rail in chairs substituted. The only recommendation the flat-footed rail had appeared to be its smaller cost in the first instance. It was more difficult to maintain and did not make so elastic a road. The cost per ton for rolling a flat-footed rail was more than that of a double or bull-headed rail, and the chair rail was taken out and replaced much quicker than a flat-footed one.

He had always found that, with heavy traffic, the second head of a wrought-iron double-headed rail, when turned, had lasted as long as the first. This was the case with all the rails laid down at Stepney. There was, however, no advantage in making a double-headed steel rail. Almost all of the relaying of the Great Eastern railway was being done with steel bull-headed rails.

Mr. Cowper observed that the question of the amount of carbon in steel had been thoroughly investigated, and a great amount of evidence on the subject would be found in the Transactions of the Iron and Steel Institute. He wished to draw attention to the fact, that inasmuch as there had been thousands of tons of steel rails made in early times by the Bessemer process, without sufficient manganese to give the best results, it was necessary to be very careful in comparing the results of the wear of steel rails having different proportions of carbon in them; it was especially so when the rails contained other impurities, such as sulphur, phosphorus, silicon, &c., as manganese was a great corrective of their evil influences, and good ingots, that would bear hammering, cogging, and rolling, could be made when sufficient manganese was used, in cases where they could not be without. He had seen bad crop ends, 3 feet long, when sufficient manganese was not used, and again the circumstances totally changed and good ends made with a more liberal use of manganese. It was not, however, altogether a question of the amount of manganese in the finished steel, and he believed that in the Bessemer process some of the manganese used was not found in the finished steel, but did excellent service in the converter, by uniting with the silica and forming a slag with it, thus purging the steel of silica, whilst some portion of the manganese also effected good by absorbing the oxygen from "overblown" particles of iron, which would otherwise have set up ebullition by forming carbonic oxide with a portion of the carbon, and thus causing honeycomb. Another point that could not be too carefully guarded against was, that of comparing rails that had not been treated in precisely the same manner; thus one might be thoroughly annealed, and even kept warm for a time in the midst of a large heap of red-hot rails, and another, precisely like it, might be chilled to such an extent as to be rendered considerably harder. It was, however, a fact that good steel, with 0·1 or 0·2 per cent. of carbon, might be heated and quenched with impunity; but with 0·3 per cent. of carbon the steel might harden or not, he believed, according to whether it contained other substances or not. Manganese was important in steel having a low amount of carbon, as well as to give toughness to steel having a higher percentage of carbon together with impurities. There was now no difficulty in making a regular uniform quality of steel plate with a very low portion of carbon in it, and thousands of such plates, having greater ductility than iron, had been made without a failure. He exhibited a piece of rail of a section designed by the late Mr. John Braithwaite for the Colchester branch of the old Eastern Counties line, which was laid in 1843 and taken up in 1868. It was a Low Moor rail, and showed no spreading or lamination; a layer of $\frac{5}{16}$ inch had worn fairly away, and the rail was of as good a shape as ever. The section was adapted for giving a suitable support to the wearing surface.

Mr. Riley said, as he had analysed rails for Mr. Price Williams, and had not only examined them chemically, but, as far as he could, mechanically, he might be permitted to make a few remarks on the condition of the rail and on the carbon question. Engineers might be somewhat perplexed by the statement that the results given confirmed the remark made by Mr. J. T. Smith, M. Inst. C.E., that greater hardness of material did not conduce to the longevity of steel rails. He did not quite agree with Mr. Price Williams on that subject. The question was, did the percentage of carbon necessarily indicate hardness of rail? He thought not. Mr. Menelaus, M. Inst. C.E., than whom, perhaps, there was no better authority in the country, had said not long since that it was due to the engineers that the steel rails now made did not stand as they formerly did. He attributed it to the falling-weight test that engineers insisted upon, which required the manufacturer to put less carbon into the rail, and so to make a softer and tougher material. It was perplexing to find two eminent authorities disagreeing on such a point; and the question was how the two statements could be reconciled. Did it necessarily follow that because a rail contained a certain amount of carbon it had a certain amount of hardness? He believed not. The rails from the Great Northern line had been sent to him with the remarks of the engineer, and they were carefully analysed by himself, his experiments being verified by the colour test applied independently by another person. It would be seen from the figures that the percentage of carbon did not necessarily indicate the hardness of the rail. Taking the rails shown in Table 7 it would be seen that the analyses were exactly the same; for although it might be said that there was a difference of 0·02 per cent. in carbon, he could say, as a practical chemist, that it was impossible to come nearer than about 0·02 per cent. One of these rails was hard and the other soft. They were quite different mechanically; but chemically they were the same. He was inclined to think that it was not so much the percentage of carbon as the way in which the rails had been cooled that should be taken into consideration; 0·40 per cent. of carbon would give a very hard rail. He had had pieces of rail sent to him containing that amount of carbon, and they could only with difficulty be touched with a tool; and, on the other hand, he had had a steel bolt containing 0·8 per cent. of carbon which he could drill easily. If a rail were made with from 0·2 to 0·3 per cent. of carbon, and cooled when red-hot in water, a tough and moderately hard material would be obtained. The rails that had been referred to as having been put into cold water and punched contained rather under 0·2 per cent. of carbon. Mr. Smith's test in reference to punching rails appeared to him to be a most valuable one. If the rails were hardened as he suggested, and contained 0·35 or 0·4 per cent. of carbon, he believed the material would break the tool

He had come to the conclusion, from many examinations, that the fair average life of a steel rail was represented by a wear of $\frac{1}{16}$ inch for each 5,000,000 tons passed over it. The table for the Metropolitan railway gave nearly this. The Great Northern, Table 6, eliminating No. 24 rail (which had most likely been changed), showed a life of 4,376,571 tons for each $\frac{1}{16}$ inch wear of the table. Nearly the same result was obtained with the Crewe rail, C, Table 5, although perhaps it could hardly be taken as a guide, as all the rails drawn had been worn out, so far as the main line was concerned, long before they were taken up, owing to the want of more rigid fishing.

Railway engineers had to think not only of the wear, but of the safety of a rail. He had known rails break in two on being dropped from a truck to the ground; and it certainly would not be safe to put such rails on any main line. Fishing the joints carefully was highly conducive to the longevity of the rails, and this, he thought, had not been hitherto sufficiently considered, nor the most suitable form of rail for fishing. He had tried to design rails for the renewals, so that the fish-plates should rest on angles instead of curves. The fish-plates were of a deep form which came below the rails: they weighed 48 lbs. a pair, and were 20 inches long. When tested with 5-feet bearings by Mr. Kirkaldy they showed about 67 per cent. of the strength of the rail. He laid the sleepers 2 feet 8 inches apart from centre to centre, and put nine sleepers of 12 inches by 6 inches to a rail 24 feet long. The equal spacing enabled the long fish-plate to be inserted. The original road had been laid with fishes 16 inches long, but as the depth between the head and flange was small the joints soon gave way, and the rails showed signs of wear towards the end, or where the wheels left one rail and reached the next. This, in a few months, extended over a length of about 1 foot, the ends of the rails being worn down nearly $\frac{1}{8}$ inch. Recently he had a large number of broken and cracked rails, resulting from their having been punched, which had all given way along the fish-holes, showing an incipient fracture, that had extended. He did not think that punching a small hole and subsequent drilling would be so trustworthy as complete drilling; it was impossible to punch a hole of less diameter than the thickness of the web of the rail, and if the web was $\frac{3}{4}$ inch thick the hole punched must be $\frac{3}{4}$ inch in diameter, so that enough metal would not be left for the removal by drilling of the portion damaged by the punch.

Mr. Bramwell mentioned an old project of his for doing away with crop ends, and with the risk of having bad ends to the rails, arising from a desire to minimise cropping as much as possible. It had been stated by Mr. May how, when cogging was done by rolls instead of by hammering, there was a concave end to the bloom, and that when the rail was finished this concavity became rolled out into an imperceptible crack, which, if a large crop end were not cut off, was left in the rail and injured it, manifesting itself in work. Mr. Bramwell's proposal, which he hoped some day to see carried into effect, was to manufacture rails as weldless and endless tires were manufactured; that was to say, by rolling each rail in a hoop form, then cutting it open, and rolling it out straight. In such a mode of manufacture there would be no crop end and no unsound part, because a hoop, having neither beginning nor end, would be uniform in quality throughout.

Dr. Siemens said there seemed to be a great divergence of opinion with regard to the quality of steel composed of different percentages of carbon. Mr. Riley, who had given considerable attention to these questions, no doubt could have supplemented the information by further chemical details, which perhaps he did not like to do because there was at present doubts as to the specific effect produced by other materials, such as phosphorus, sulphur, silicon, &c. Dr. Siemens might perhaps be able to supply some data regarding steels in which the proportions of different materials reached their limits on the one side or on the other. It had been said that steel containing a considerable percentage of carbon, 0·4 per cent., was very soft. That might be partly owing to the tempering, for if the steel had been slowly cooled it would be soft, but it might also be owing to the manner in which the carbon was combined. Carbon was not always chemically combined even in steel. In the process of mixing spiegeleisen with the blown metal at the last moment in the Bessemer process there was hardly time to form a chemical combination, and hence metal might be produced which contained a considerable proportion of carbon, and yet was essentially soft metal because the carbon was not chemically combined. He had observed, in boring a large cylinder of steel cast from metal of that description, that at one point the boring tool went deeply into the metal, and at another point there was a resistance as though the metal were hard. In such a case no effect of temperature, of sudden cooling, was involved, because of the particular form of the metal. The phenomena showed clearly that steel was not always homogeneous unless special care had been used to make the mixture perfect. Mr. Cowper had attributed to manganese the quality of making the metal tough, whereas carbon made it hard. That was not universally the case. In the case of steel containing as much as 0·4 or 0·5 per cent. of carbon, little manganese was desirable or necessary to make the metal forge properly; but in the case of very soft metal, and metal containing phosphorus, the manganese was an essential condition. For instance, 0·2 per cent. of phosphorus, which was about the maximum amount admissible, necessitated about 0·4 per cent. of manganese to make the metal at all workable and to prevent its extreme brittleness when hard; but in metal containing hardly any carbon, less than 0·1 per cent., manganese was of the utmost importance, and without it the metal could not be got to work or stand against the grinding axle. The manganese seemed to bind the particles of metal together, and to make it more homogeneous. Mr. Riley had mentioned the difficulty of determining such a slight amount of carbon by the ordinary colour test. No doubt the difficulty was great, but Mr. Willis, of the Landore Works, had introduced a test for determining a very slight proportion of carbon, sufficiently accurate for all practical purposes, by dissolving the metal in nitric acid and observing the effect of colour on the solution. The nitric acid did not act upon the carbon, and it produced a brown tinge of sufficient intensity to be distinctly observable, even though the proportion of carbon should be considerably below 0·1 per cent. This test would enable manufacturers to produce steel of extreme mildness, such as was now used largely for engineering purposes. It was impossible to estimate so slight a difference in carbon as 0·05 or 0·1 per cent. by any mechanical test; but by a ready chemical test of that kind the manufacturer was enabled to bring the metal down to an exact point considerably below 0·1 per cent. No doubt these questions were at present only partially understood, and much work was still required in order to arrive at certain conclusions regarding the conditions necessary to produce steels of definite qualities. If steel was produced from pure iron, such as was found in Sweden, a metal could be made containing hardly any manganese, and only a trace of carbon, and no appreciable percentage of phosphorus or silicon; and metal of that description, which was as nearly as possible of pure iron, was perhaps the toughest that could be made, exceeding in toughness copper or even silver. A further advantage of such metal was that it was less liable to rust. Experiments lately made in France showed a percentage of rust, as compared with wrought and cast iron, in the proportion of 0·4 to 1·4, being much in favour of a pure metal such as a very mild steel—a quality of great value for shipbuilding and purposes of that kind.

Mr. Brunlees had on a former occasion expressed the opinion that the fish-joints of railways were the most unmechanical things connected with them, and he had no hesitation in repeating the statement. He thought there was room for improvement in fish-joints, and he was glad to find that the attention of Mr. Tomlinson was directed to the subject. He considered the best rail was that which had plenty of metal in the head and a small proportion in the foot, forming what he would call a girder section. In that case the metal was properly distributed, and both the tension and the wearing part were where they ought to be. If such a rail was more generally adopted, better results would be obtained. He knew of no form of permanent way better or stronger than that of smaller dimensions, which he had used in 1852 and ever since, both at home and abroad, with excellent results.

Mr. Riley said it was certainly an omission on his part not to have mentioned the different conditions in which the carbon existed in steel rails; but, having so many analyses to make, he had not been able to complete the tests, but he intended to do so.

Mr. Sandberg observed, through the Secretary, that few, if any, foreign governments or departments of public works could show information of equal value to the statistics collected by the Author, and illustrated in this and other Papers on the railways of Great Britain. The Paper entered into the metallurgy of iron and steel as applied to railway bars, a subject which he had made his speciality, and he would therefore offer some remarks, based upon his practice as inspector of rails for seventeen years for the Swedish government and other railways. The Paper furnished ample proof of the superiority of steel to iron for railways, unless the traffic was very light. The price of steel rails had been reduced during the last ten years from double that of iron to only 25 per cent. more than the price of iron, but he feared at the expense of their quality. Since it had been attempted to produce steel rails of inferior and cheaper raw material, engineers should be on the look-out for their safety more than for their durability, as they and not the makers were answerable for the consequences. Owing to the great competition now existing in a slack state of trade, the tendency was to cheapen the make and to "avoid loss" by manufacturing rails regardless of their safety, which in his opinion was of greater importance than durability. With this view he would warn railway authorities, particularly those who, like his friends, had to contend against a cold climate, not to sacrifice the safety, tenacity, stretch, or extensibility of the steel for greater durability through hardness; all the more so if this hardness was produced by phosphorus or silicon, which also made it brittle, instead of by carbon and manganese. It had been stated that an amount of 0·2 per cent. of phosphorus was the maximum admissible, but only half that could be safely tolerated for a cold climate, admitting, however, that the smaller the amount of carbon the greater could be the amount of phosphorus in the steel without brittleness. Hard steel could be rolled better than soft. There was some difficulty in determining the amount of carbon in steel by the Eggertz coloration test when the amount was small, but Professor Eggertz had lately told him that sufficient accuracy for all practical purposes could be obtained if the solution was made at a temperature of 176° Fahr., and also if no light was admitted during the process, for which purpose a special apparatus had been constructed.[1] He had supplied standard steel, obtained direct from Professor Eggertz, to many steel-makers, in order to facilitate the testing of every cast, but he was sorry to find that there were still many steel-works without either a laboratory or a chemist, which he thought highly necessary in these experimental times. In his opinion the cogging was a more severe test for the steel, as generally it gave more wasters than the hammer, which latter would only work steel somewhat red-short into clean rails. He thought that drilling was safer than punching rails; still, if the steel was soft and the hole not too near the end, so as to leave, say, a depth of 1½ inch of solid metal in the web of the rail, punching was safe enough. Another means to obviate the breakage of iron or steel rails in the punch-holes was to prevent the blow against the bolt on the upper part of the hole every time the train passed over the joint by making it as stiff as the solid rail; the ordinary weak joint was no doubt the cause of that mischief. He had tried many experiments both by dead weight and blow on the strength of rail joints,[2] and could confirm Mr. Brunlees' opinion as to the inferiority of the ordinary rail joint. For existing lines, with the joint sleepers as close as practicable, angle fish-plates having 67 per cent. of the stiffness of the solid rail would probably be the best. Such were now laid on the Swedish State railways without base-plates, extending vertically to the flange of the rail and horizontally to allow four holes for spikes to be punched through the flange so as to nail them both inside and outside to the sleeper; thus the road would be better kept both horizontally and vertically than by the ordinary fish-joint. For lines in construction the best joint, in his opinion, would be a fish-plate of such depth as to afford the same stiffness and elasticity to the rail joint as the solid rail with the same distance of joints as of sleepers, say 3 feet from centre to centre. With such a fish-joint applied to a rail-section of small fishing angles, say from 11° to 15°, so as to throw less work upon the bolt than with the pear-formed rail-section of 30°, neither breaking of bolt-holes in the rail, nor sinking of the joint, with too early failure of the rail ends and rolling-stock, would be risked, and this would, in his opinion, materially reduce the maintenance and renewals, and increase the money life of the permanent way.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 411.

[2] *Vide* "Engineering," 25 November, 1875.

Mr. R. H. Tweddell remarked, through the Secretary, that a large portion of the cost of maintenance and renewals of the permanent way of railways had been shown to be due to the fact that the crossings, as now made, formed their weakest part. He believed that the continuous crossing, designed by the Author some years ago, in order to remedy this defect, effectually preserved what might be termed the 'continuity of elasticity' of the line, obviating the objectionable anvil-like action of cast-steel crossings, and the looseness and want of continuity of the ordinary forms; but the cost of manufacture had hitherto prevented its being offered at a price sufficiently low to insure its general adoption. Again, in the previous form of these continuous crossings, a special or solid section of rail had to be used, to insure sufficient material in the web after the groove was slotted out, and involving special machining at each end to enable the connection to be made to the next rail by the usual fish-plate. Hence it occurred to Mr. Price Williams that hydraulic pressure might be adopted to make these crossings, and Mr. Tweddell had designed a machine for this purpose, and had successfully applied it to some Landore Siemens' steel rails of the 80 lbs. double-headed section, which were passed through a special set of dies and stamped into the finished form. The question was simply one of forming the dies so that portions of the rail were forced to flow while hot into spaces prepared for them: thus the material was moved from where it was not required, and utilised by being placed where it was specially wanted to strengthen the rail, so that the crossing became uniform and equally elastic with the rest of the permanent way. A saving of 50 per cent. was effected in the first place in the material of the crossing, inasmuch as the weight of solid rail, as compared with the ordinary rail, now required was as 120 to 80: and finally all machine-work was dispensed with, as the squeezing was done at one blow. In Mr. Tweddell's opinion, it was difficult to place any limit to this illustration of the practical application of M. Tresca's researches on the flow of solids; and he believed by this process wrought-iron or steel railway chairs might be made almost as cheap as cast-iron ones. Should this prove to be the case, further economy would be effected in the maintenance of permanent way.

May 30, 1876.

JAMES ABERNETHY, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected:— George Frederick Adams, George Baird, Samuel Bailey Coxon, Edward Easton, and William Sullivan Harington, as Members; James Butler, Frank Stuart Courtney, Stud. Inst. C.E., Henry Dangerfield, Arthur George Fenn, Henry Gooch, Edward Fyfe Griffith Griffith, Stud. Inst. C.E., Henry Tylston Hodgson, William Langdon, Augustus van Zandt Macdonald, William Patterson Orchard, B.E., Stud. Inst. C.E., the Hon. Richard Clere Parsons, B.A., Stud. Inst. C.E., Webster Paulson, Colonel Frederick Weston Peile, R.E., Edmund Walter Plunkett, Sidney Preston, Stud. Inst. C.E., John William Randell, Stud. Inst. C.E., John Shaw, Alexander Smith, Arthur Toulmin Smith, Stud. Inst. C.E., John Philip Spencer, Sydney Stent, Major Edward Harding Steward, R.E., Alfred Thorne, Robert Charles Turner, Charles Henry Alexander Twidale, and Clement Heatherly Wilmot, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred James McNair Harkness, Philip Causton Lockwood, Richard Proctor-Sims, and James Nelson Shoolbred, B.A., from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:— Robert Sinclair Campbell, Patrick Edward Dove, Francis Joseph

EDE, THOMAS LINDSAY GALLOWAY, M.A., ROBERT GRINDLE, ROBERT COLLETT MAWSON, AMYAS MORSE, CHARLES ANTHONY STOESS, ALGERNON ROBERT SUTHERLAND, and BENJAMIN HOWORTH THWAITE.

The discussion upon the Paper, No. 1,479, on "The Permanent Way of Railways," by Mr. R. PRICE WILLIAMS, occupied the whole evening.

June 1, 1876.

THE Session was concluded by a Conversazione, which was given by the President and Mrs. Stephenson at the South Kensington Museum, by permission of the Lords of the Committee of Council on Education. In addition to the members of all classes of the Institution invitations were sent to and were accepted by a numerous circle of distinguished men of science and others; and in every case the card of invitation admitted a lady.

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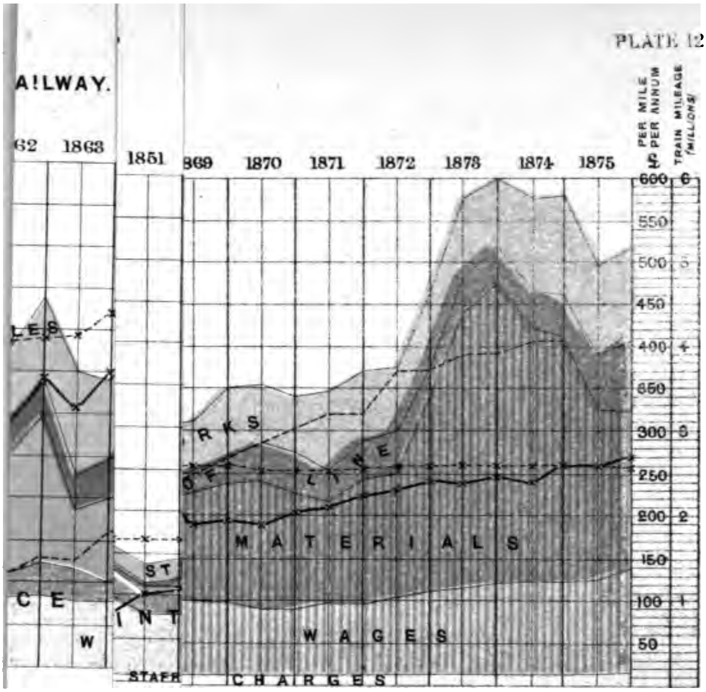
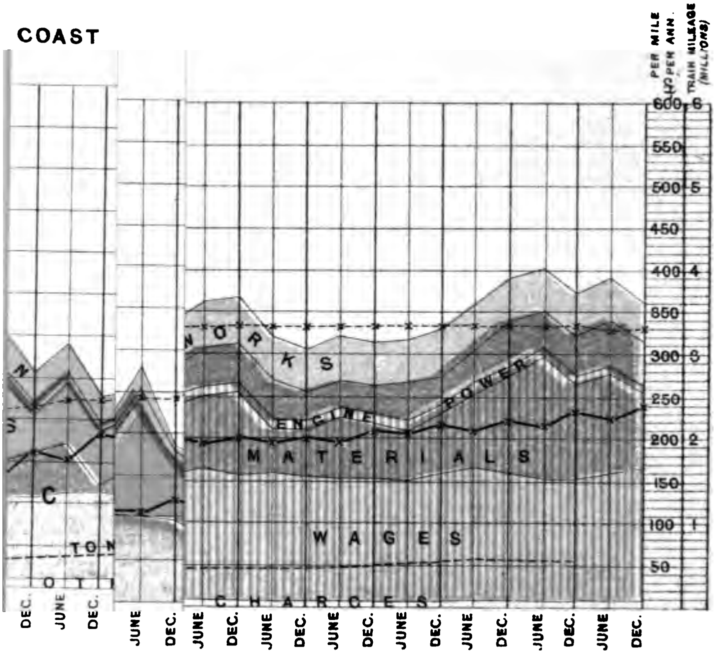
PLATE 12

AILWAY.



COAST



ports.

4.

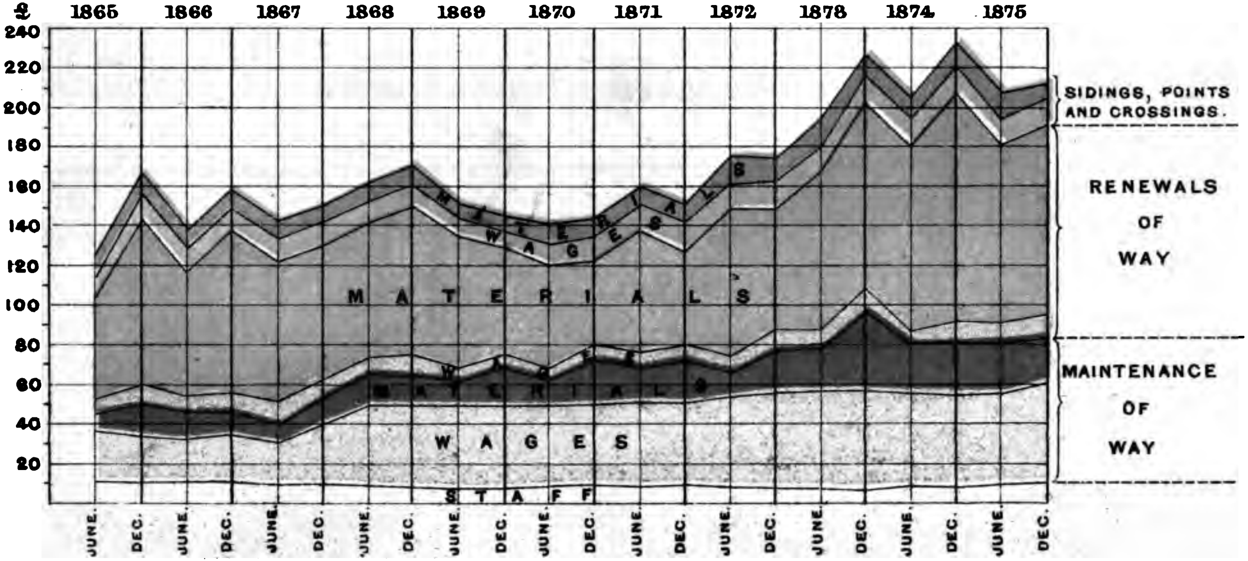
THOS KELL, LITH. 40, KING ST, COVENT GARDEN.

OF

THE PERMANENT WAY OF RAILWAYS.

GREAT NORTHERN RAILWAY.

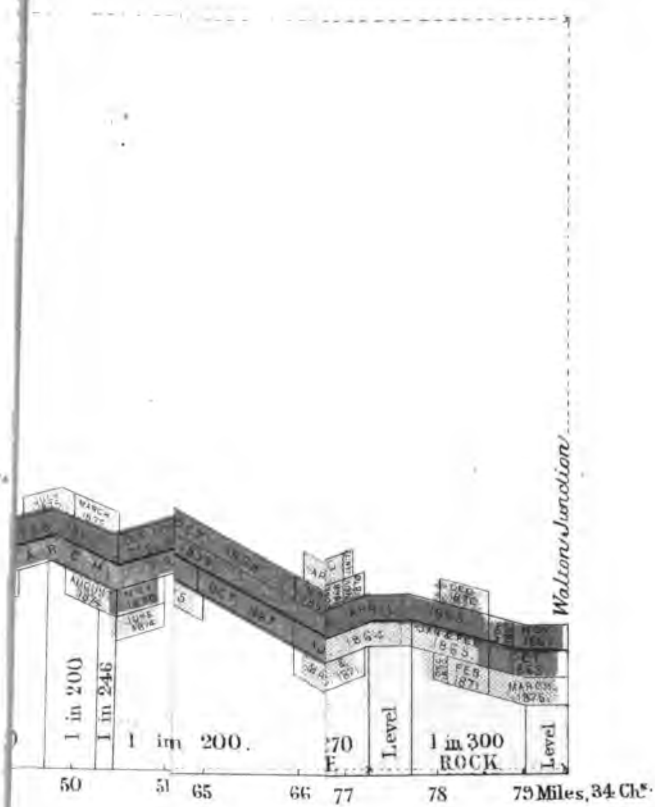
COST PER MILE PER ANNUM OF STAFF, MAINTENACE OF WAY, RENEWALS OF WAY & SIDINGS, POINTS, & CROSSINGS FROM JUNE 1865 TO DEC: 1875 (INCLUSIVE)

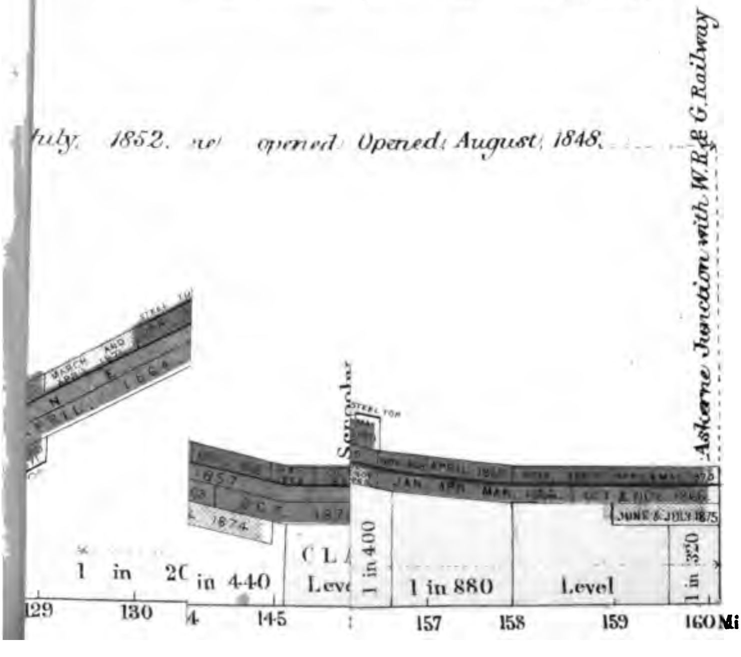


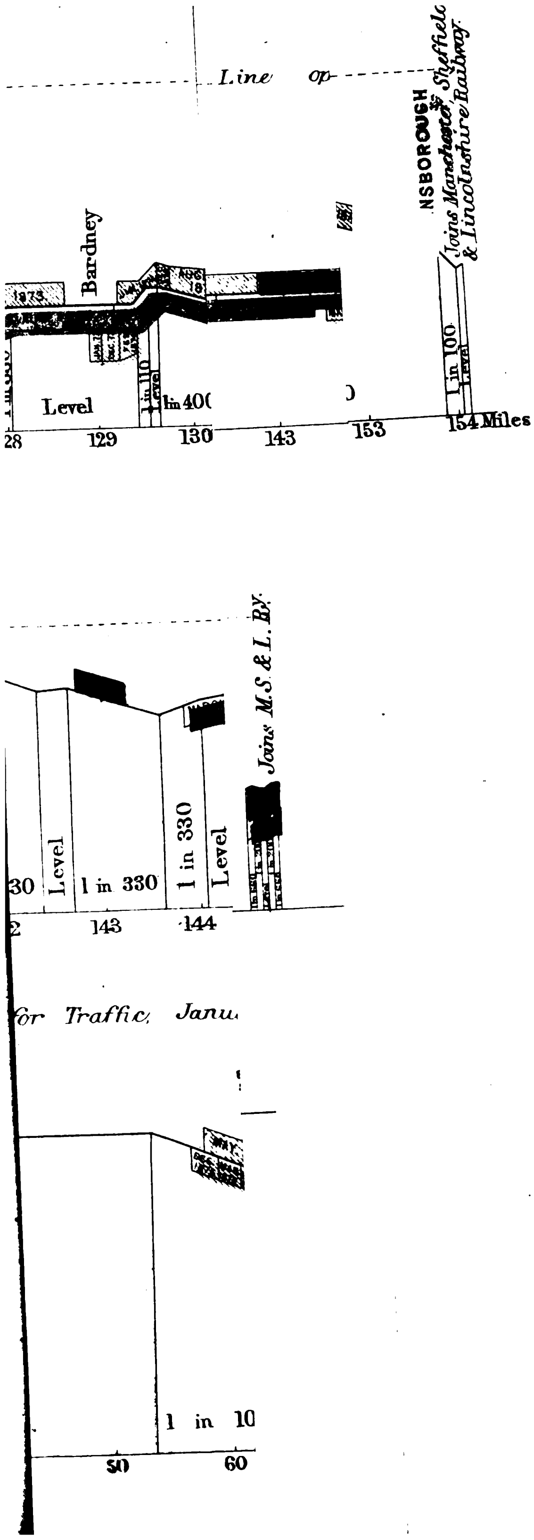
R. PRICE WILLIAMS, DELT

Minutes of Proceedings, Institution of Civil Engineers, Vol. XLVI. Session 1875-76. Part 4.

THOS KELL, LITH. 40, KING ST COVT GARDEN.


MARCH 1875
AUGUST 1874
JUNE 1874
APRIL
1864
1865
JAN & FEB 1865
FEB 1871
MARCH 1876
OCT 1863
NOV 1867
Walton Junction
1 in 200
1 in 246
1 in 200.
270
E
Level
1 in 300
ROCK
Level
50
51
65
66
77
78
79 Miles, 34 Chs.


July 1852.
opened
Opened August 1848.
Askerne Junction with W.R.& G. Railway
STEEL TOP
MARCH AND 1875
1864
1857
OCT
1874
JAN. APR. MAR.
OCT & NOV 1866
JUNE & JULY 1875
1 in 20
in 440
CLA
Leve
1 in 400
1 in 880
Level
1 in 320
129
130
145
157
158
159
160 Miles, 10 Chs.

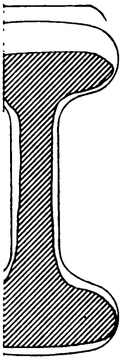


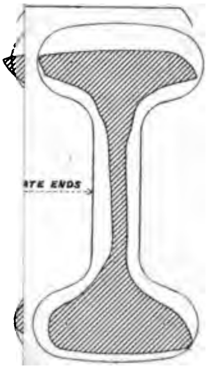
UNIV. OF MICH

STREET, COVENT GARDEN.

PLATE 18.

TEEL RAILS ON T





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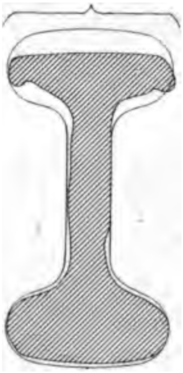

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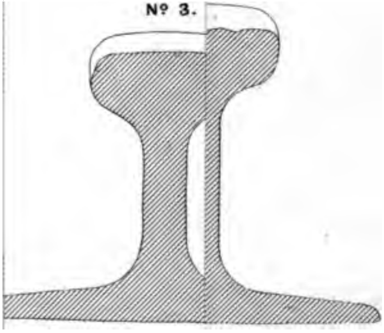
Nº 3.



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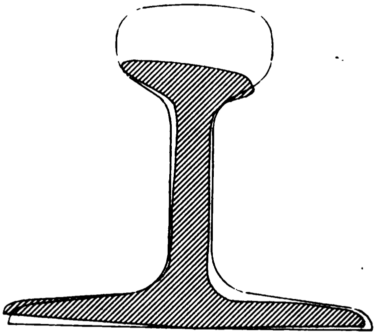
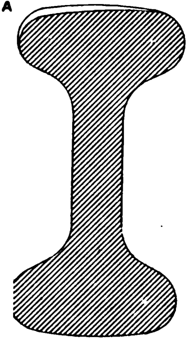


.WAY. *(Section referred to in Table Nº 11.)*

SOUTH EA



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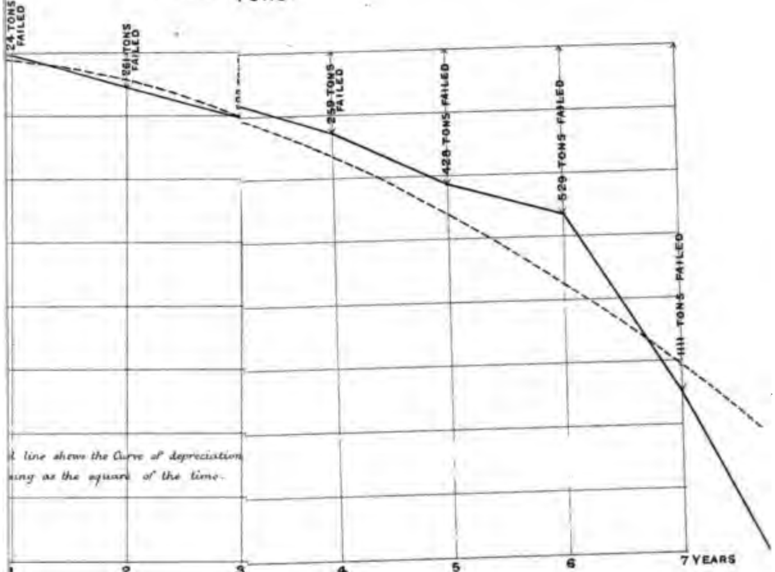
THOS KELL, LITH 40, KING ST COVENT GARDEN

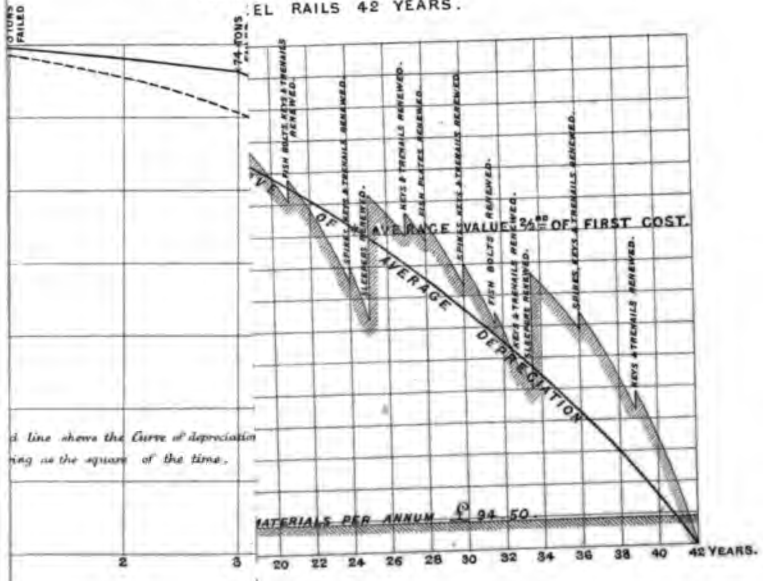
PLATE 20.

DIAGRAME GREAT NORTHERN RAILWAY.

22ND 1865_ GUARANTEED 7 YEARS
CONTRA TONS.



CONTRACT OF SEF OF DEPRECIATION OF A MILE OF PERMANENT WAY.
1400 SLEEPERS 8 YEARS.
EL RAILS 42 YEARS.



7o Part 4.

THOS KELL, LITH, 40 KING ST COVENT GA

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